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Introduction

The first meeting of radiolarian micropaleontologists was organized in 1978 by P. De Wever (Lille, France). Most participants being from European universities, the name of "EuroRad" was coined to designate this meeting and the following ones. EuroRad II was held in 1980 (Basel, Switzerland), EuroRad III in 1982 (Bergen, Norway), and EuroRad IV in 1984 (Leningrad, USSR). More and more radiolarists from all continents joining the EuroRad group, a formal international association of radiolarian micropaleontologists was created and its first meeting (InterRad V) was held in 1988 at Marburg (Germany) followed by InterRad VI in 1991 (Firenze, Italy), and Interrad VII in 1994 (Osaka, Japan).

The last InterRad VIII meeting (almost twenty years after Eurorad I) was held from September 8th to 13th (1997) at the Château de Bierville, a meeting centre located 50 kilometers South of Paris (France). 85 participants from 17 countries attended 8 workshops and presented 144 oral communications or posters. The abstracts of the communications were published in a special volume before the meeting, and further distributed to a total of 200 scientists. A one day special excursion was organized during InterRad VIII including a well-appreciated visit of a winery in the Loire area including some wine tasting, and a visit of the Château de Chambord, a gorgeous Renaissance castle.

During the meeting, 23 papers were offered for publication in a special issue of *Geodiversitas*. A grand total of 21 manuscripts were received by the editorial committee and submitted to a pair review. Finally, 14 publications were selected and are presented in this volume.

Two years after InterRad VIII, this special issue of *Geodiversitas* cannot reflect the wide scope of the communications that encompassed all the geological record from Cambrian to Present. Original information is, however, given about significant advances in radiolarian biostratigraphy of Mesozoic formations of the Antartic and Pacific domains. New taxonomic descriptions of Paleozoic and Mesozoic forms are presented. A single paper is devoted to the radiolarians of the Messinian diatomites of the Mediterranean area. As usual, publication delay was longer than expected due to several reasons: some authors were late submitting their manuscript, some reviewers took a lengthy time to review manuscripts and answer successive requests from the editor. Modifications requested by reviewers took some extra time to be completed.

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Patrick De Wever and Jean-Pierre Caulet

Non-Tethyan Triassic Radiolaria from New Zealand and northeastern Siberia

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ABSTRACT
Well-preserved Middle Triassic radiolarian faunas have been documented from phosphatic nodules collected from the Waipapa Terrane, New Zealand and the Omolon Massif, northeastern Siberia, respectively. Both New Zealand and northeastern Siberia faunas include many species that are well-known from European Tethys area, including *Silicarmiger costatus costatus* Dumitrica, Kozur & Mostler, 1980 which indicates an early Ladinian age. These Tethyan species occur with abundant non-Tethyan radiolarians that are characteristic of these faunas. Distinctive pylomate spumellarians are described herein as a new genus *Glomeropyle* Aita & Bragin. This genus has not been recognized in Middle Triassic sequences of Europe, Japan, Southeast Asia or North America. Seven new Middle Triassic species are described: *Glomeropyle aurora*, *Glomeropyle boreale*, *Glomeropyle poinui*, *Glomeropyle* (?) *galagala*, *Glomeropyle grantmackiei*, *Glomeropyle mahinepuaensis*, *Glomeropyle waipapaensis*. They do not have Tethyan affinities and are only known from northern and southern high latitudes. They are Triassic Radiolaria with a bipolar distribution pattern.

KEY WORDS
Radiolaria,
non-Tethyan,
Middle Triassic,
New Zealand,
Siberia,
new species,
Glomeropyle n. gen.

RÉSUMÉ

Radiolaires triasiques non téthysiens de Nouvelle-Zélande et du Nord-Est de la Sibérie.

Des radiolaires bien conservés du Trias moyen ont été découverts dans des nodules phosphatés provenant des formations Waipapa, en Nouvelle-Zélande et du massif Omolon, au Nord-Est de la Sibérie. Les deux faunes comprennent de nombreuses espèces bien connues en Europe de la zone téthysienne, incluant *Silicarmiger costatus costatus* Dumitrica, Kozur & Mostler, 1980 qui indiquent un âge Ladinien inférieur. Ces espèces téthysiennes existent avec de nombreux radiolaires non-téthysiens, caractéristiques de ces faunes. Parmi eux des spumellaires à pylome sont décrits dont le nouveau genre *Glomeropyle* Aita & Bragin. Ce genre n'avait pas encore été trouvé dans les séries du Trias moyen d'Europe, du Japon, d'Asie du Sud-Est et d'Amérique du Nord. Sept nouvelles espèces du Trias moyen sont décrites : *Glomeropyle aurora*, *G. boreale*, *G. poinui*, *G.* (?) *galagala*, *G. grantmackiei*, *G. mahinepuaensis*, *G. waipapaensis*. Elles n'ont pas d'affinités téthysiennes et sont seulement connues dans les hautes latitudes (Nord et Sud). Ces faunes triasiques ont donc une distribution bipolaire.

MOTS CLÉS
radiolaires,
non-Téthys,
Trias moyen,
Nouvelle-Zélande,
Sibérie,
nouvelle espèce,
Glomeropyle n. gen.

INTRODUCTION

In recent years radiolarians have provided valuable information on the age of previously undated strata, improvements to correlation both within terranes and between terranes, and in the assessment of paleobiogeographic affinities (Aita & Spörli 1992, 1994). Recently, distinctive non-Tethyan radiolarian faunas have been found in Middle Triassic strata in both New Zealand and northeastern Siberia (Fig. 1), (Aita *in* Matsuoka *et al.* 1996: 204-206; Bragin *in* Matsuoka *et al.*

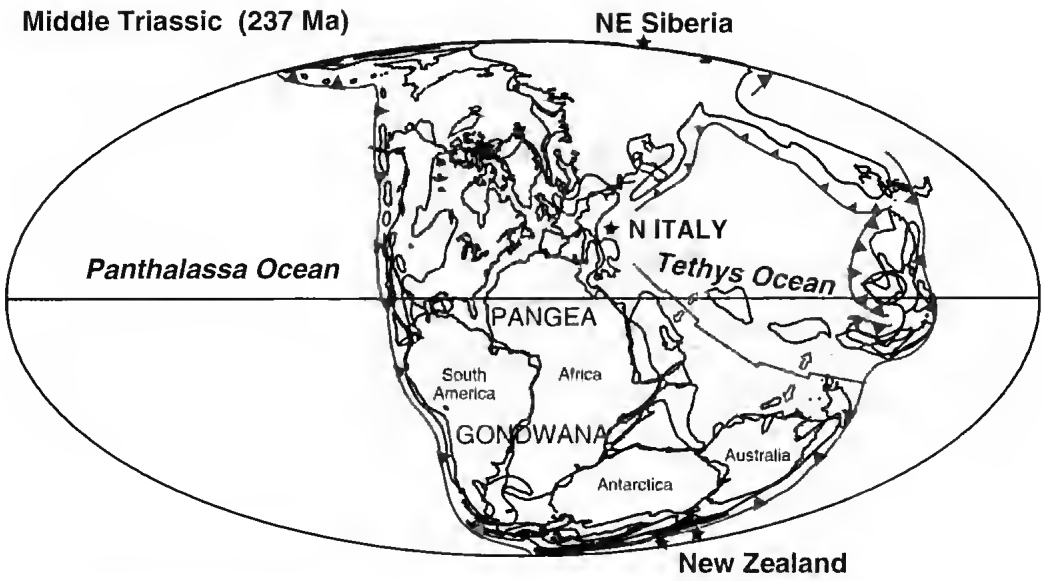


FIG. 1. — Paleogeographic map of the Middle Triassic (Ladinian-Anisian) at 237 million years ago (Ma), showing localities cited in this study in New Zealand, northeastern Siberia and northern Italy (modified from Scotese 1997; Smith *et al.* 1994).

1996: 209). Although geographically distant, the faunas of both areas are very similar and almost of correlative age. They both include distinctive spumellarians with pylome. These taxa have never been reported from Tethyan areas (Dumitrica *et al.* 1980; Kozur & Mostler 1994; Kozur *et al.* 1996; Dumitrica pers. comm.), Japan (Yao 1982; Sugiyama 1997; Ohtaka *et al.* 1998), or the Philippines (Yeh 1990). In this paper, we describe and illustrate these high-latitude taxa, including one new genus and seven new species. In addition, we briefly summarize the lithostratigraphy of the radiolarian-bearing sequences in New Zealand and in northeastern Siberia.

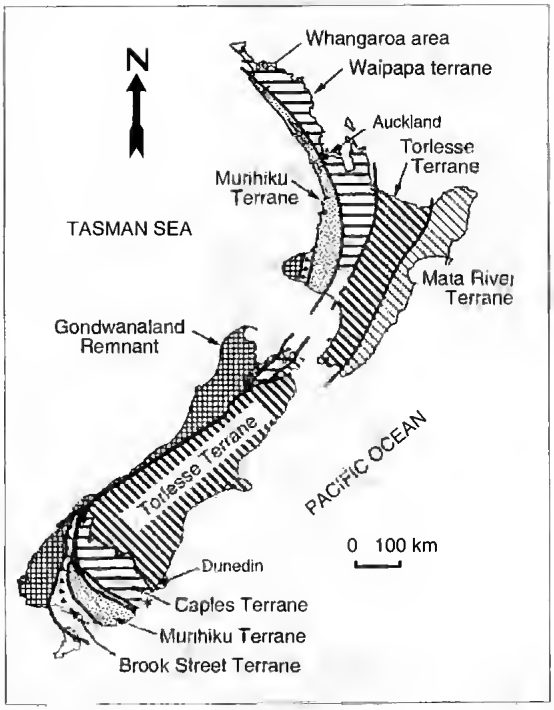


FIG. 2. — Map showing basement terranes of New Zealand and location of Whangaroa area (squared area) in the Waipapa Terrane, modified from Aita & Spörli (1992) and Roser *et al.* (1993). *, Bull Creek in the Caples Terrane.

TRIASSIC RADIOLARIA IN WAIPAPA AND CAPLES TERRANES, NEW ZEALAND

WAIPAPA TERRANE, MAHINEPUA PENINSULA, NORTHLAND

The Waipapa Terrane is one of five Mesozoic terranes recognized in the North Island, New Zealand (Fig. 2). It lies in the northeastern and central part of the North Island and consists of spilitic basalts, radiolarian cherts, green argillites, and terrigenous clastics (Aita & Spörli 1992). Although these rocks are metamorphosed to

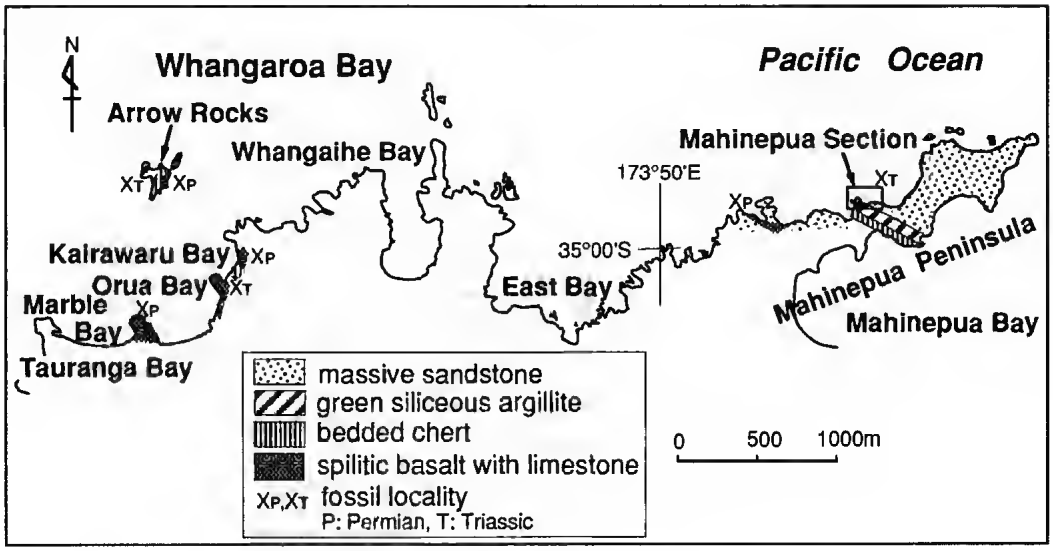


FIG. 3. — Geological map of the Whangaroa area, Northland, New Zealand and location of the Mahinepua Section (squared area) in the Waipapa Terrane, and fossil localities. XP, Permian age; XT, Triassic age.

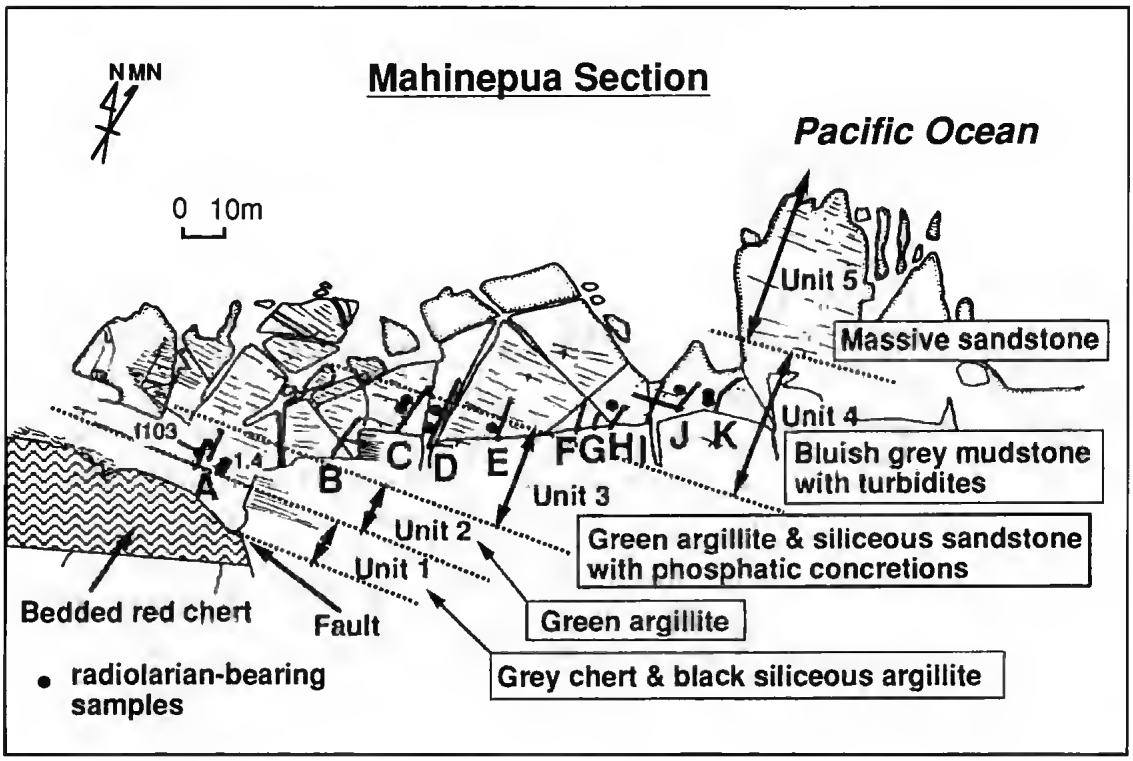


FIG. 4. — Geological sketch map showing wave-cut bench exposures on Mahinepua Peninsula, Northland, New Zealand. Five stratigraphic units are recognized. Measured sections from A to K and location of radiolarian samples are indicated. Sample PO4/f103 (= field No. MAH-3.5): Grid reference P04/88618928, Whangaroa sheet P04, New Zealand 1:50,000 topographical map series NZMS 260.

prehnite-pumpellyite facies (Black 1994), phosphatic concretions hosted within green argillite have yielded well-preserved radiolarian faunas (Sakai *et al.* 1998).

In general, the ages of the radiolarian faunas in the Waipapa Terrane show that an older Permian-Triassic complex occurs in the north and a younger, Triassic-Jurassic complex is in the south (Aita & Spörli 1992; Spörli *et al.* 1989; see also Black 1997). Both complexes consist of very similar lithologic sequences characterized by radiolarian chert, green argillite and terrigenous mudstone and sandstone although the older complex also has some spilitic basalt with associated limestone lenses.

In the Whangaroa area, located in the northern part of the Waipapa Terrane, the older Waipapa rocks are well exposed in sections at Arrow Rocks, Marble Bay, Orua Bay, Kairawaru Bay, and Mahinepua Peninsula (Fig. 3).

Bedded cherts in this area are of Late Permian age (Aita & Spörli 1992) while Late Triassic radiolarians from phosphatic concretions within green argillite at Mahinepua have been reported by Aita in Matsuoka *et al.* (1996). Detailed investigations of the Waipapa Terrane by a Japanese and New Zealand collaborative research project in 1995 and 1996 revealed that the hemipelagic green argillite at Mahinepua ranges from Middle to Late Triassic in age (Takemura *et al.* 1998).

A re-examination of the Permian fusulinid limestones from Orua Bay by Leven & Grant-Mackie (1997) resulted in the identification of *Yabeina globosa* (Yabe, 1906) and *Lepidolina shiraiwaensis* Ozawa, 1925, and established correlation with the *Yabeina-Lepidolina* zone of the Midian Stage. Leven & Grant-Mackie (1997) attribute the Midian to the Late Permian, but following Jin *et*

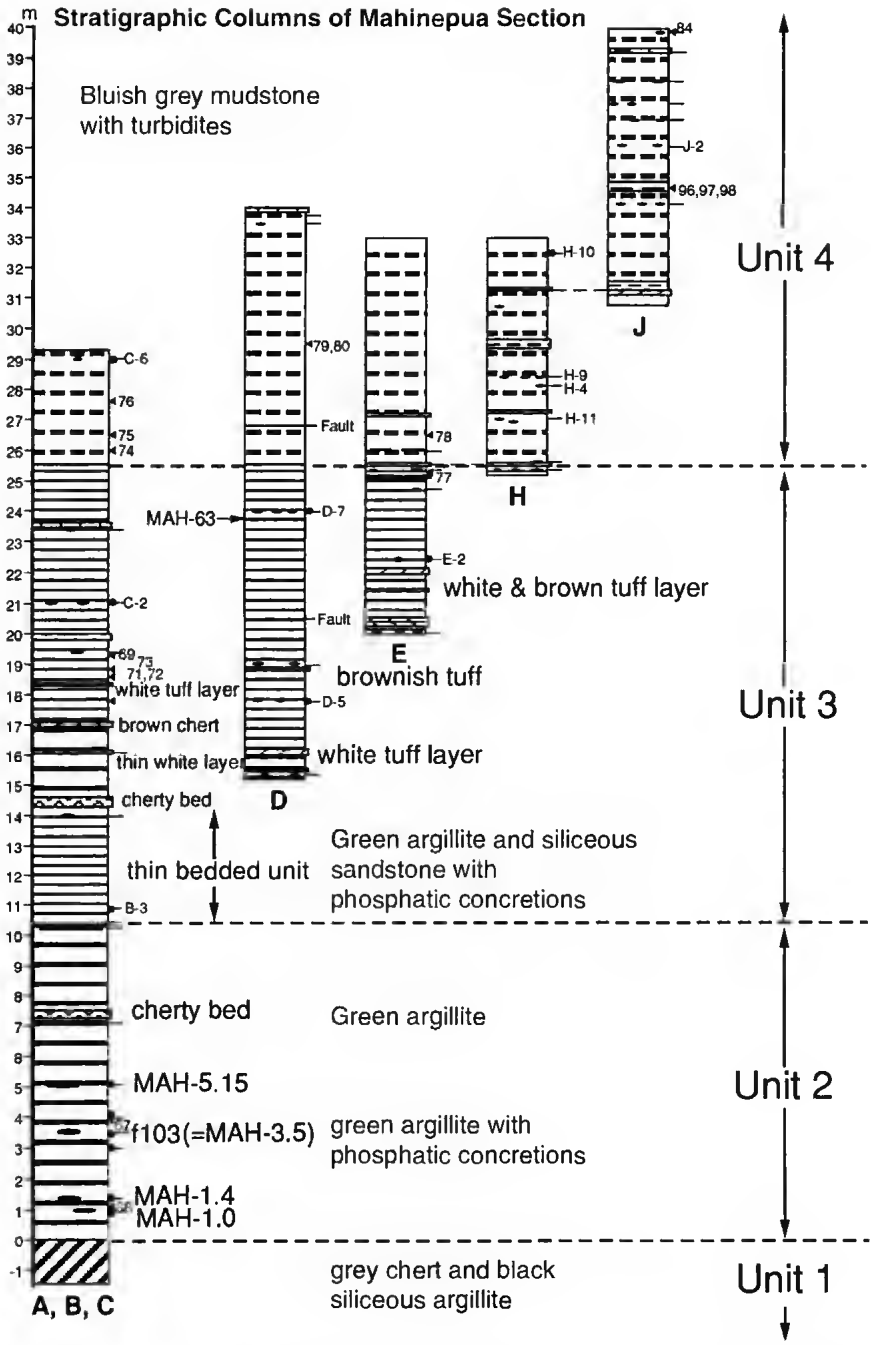


FIG. 5. — Stratigraphic columns in the Mahinepua Section, Waipapa Terrane, New Zealand. Composite columns show lithologic composition of four units and horizons of radiolarian-bearing samples.

al. (1997), the Midian is correlated with the Late Middle Permian Capitanian Stage. More recently, the lithostratigraphy and radiolarian biostratigraphy of the Late Permian to Middle Triassic succession at Arrow Rocks has been described (Takemura *et al.* 1998, 1999 in this volume).

TABLE 1. — Radiolarian faunal list for Mahinepua, Bull Creek (New Zealand) and Dzugadzak River (Northeast Siberia) and occurrence of radiolarians from Buchenstein Limestone, Recoaro (Northern Italy).

	NEW ZEALAND Waipapa Terrane	NEW ZEALAND Caples Terrane	NE SIBERIA Omolon Massiv	N ITALY Vicentinian Alps
Locality	Mahinepua	Bull Creek	Dzugadzak River	Recoaro
Sample or Unit Field No.	PO4/f103 MAH-3.5	H45f074 YABC-26	7438-89-1 Unit 10	Buchenstein Limestone
Spongopallium contortum Dumitrica, Kozur & Mostler	X			X
Spongopallium aff. *koppi* (Lahm)			X	X
Spongopallium sp.	X	X		X
Cryptostephanidium longispinosum (Sashida)	X			X
Hindeosphaera sp.			X	X
Pseudostylosphaera sp.		X		X
Eptingium sp.	X			X
Kahlerosphaera sp.	X			X
Plafkerium (?) sp.	X			X
Stauracontium (?) sp.			X	X
Archaeosemantis sp.	X	X		X
Parentactinia inerme Dumitrica	X	X	X	X
Parentactinia pugnax Dumitrica	X	X	X	X
Pentactinorbis mostleri Dumitrica	X			X
Pentactinorbis sp.	X			X
Glomeropyle aurora Aita, n. sp.	X			
Glomeropyle boreale Bragin, n. sp.	X		X	
Glomeropyle poinui Aita, n. sp.	X			
Glomeropyle (?) *galagala* Aita, n. sp.	X	X		
Glomeropyle grantmackiei Aita, n. sp.	X	X		
Glomeropyle mahinepuaensis Aita, n. sp.	X			
Glomeropyle waipapaensis Aita, n. sp.	X			
Silicarmiger costatus costatus Dumitrica, Kozur & Mostler	X	X	X	X
Silicarmiger cf. *latus* Kozur & Mostler			X	
Silicarmiger sp.				X
Foremanellina aranea Dumitrica	X			X
Foremanellina expansolabrum Dumitrica		X		X
Foremanellina sp.		X		X
Recoaroella sp.		X		X
Triassospongocyrtis sp.		X		X
Hozmadia cf *reticulata* Dumitrica, Kozur & Mostler	X			X
Hozmadia sp.	X	X	X	X
Goestlingella sp.	X			X
Poulpus sp.	X		X	X
Pachus (?) sp.			X	
Laxtorum (?) sp.		X	X	
Simple multicyrtoids	X	X		

MAHINEPUA SECTION

Mahinepua section is located on the northern side of Mahinepua Peninsula (Fig. 3), east of the Whangaroa area, North Island, New Zealand. The fossil locality is PO4/f103 (= field No. MAH-3.5), grid reference PO4/886892 in the archival New Zealand Fossil Record File maintained by the Geological Society of New Zealand, i.e. locality No. f103 in map sheet PO4 of the 1:50,000 series NZMS260. It lies in the lower part of Unit 2 (Fig. 4).

The complete section consists of red bedded

chert (20 m thick), green siliceous argillite (25.5 m), bluish grey mudstone with turbidites (30 m), and massive sandstone (> 100 m) in ascending order (Figs 4, 5). This is a typical "chert-green argillite-clastics" sequence which is considered to represent a stratigraphically continuous accretionary sequence from pelagic (bedded chert) and hemipelagic (green argillite) facies to terrigenous facies (blue-grey mudstone and massive sandstone). Black phosphatic concretions from many horizons within the green argillite yielded diverse, well-preserved radiolarian faunas of Middle to Late Triassic age.

The Mahinepua Section is subdivided into five units as follows (Figs 4, 5):

Unit 1. Grey chert and black siliceous argillite .. .. 5 m.

Unit 2. Green argillite with lenticular phosphatic bands ..... 10 m.

Unit 3. Well bedded green argillite and siliceous sandstone with phosphatic concretions and intercalated thin white tuff ..... 15 m. The lower 4 m is thin bedded.

Unit 4. Bluish grey mudstone with turbidites .... 30 m. Many turbidites layers of 10-20 cm thickness are intercalated with mudstones.

Unit 5. Massive sandstone ..... 100 m.

The radiolarian fauna in the basal part of Unit 2 includes *Pseudostylosphaera spinulosa* (Nakaseko & Nishimura, 1979), *Glomeropyle aurora* n. sp., *Hozmadia* aff. *pyramidalis* Gorican, 1990 *in* Gorican & Buser, 1990. Sample f103 (= field No. MAH-3.5) is a black phosphatic concretion taken from 3.5 m above the base of this unit and contains well-preserved Middle Triassic radiolarians. The fauna is dominated by abundant Spumellaria including *Spongopallium contortum* Dumitrica, Kozur & Mostler, 1980, *Plafkerium* (?) sp., *Eptingium* (?) sp., *Parentactinia inerme* Dumitrica, *P. pugnax* Dumitrica, 1978, *Pentactinorbis mostleri* Dumitrica, 1978, and *Cryptostephanidium longispinosum* (Sashida, 1991). In addition, *Glomeropyle aurora* n. sp., *G. poinui* n. sp., *G.* (?) *galagala* n. sp., *G. grantmackiei* n. sp., *G. mahinepuaensis* n. sp. and *G. waipapaensis* n. sp. are present. The nassellarians include *Silicarmiger costatus costatus* Dumitrica, Kozur & Mostler, *Foremanellina aranea* Dumitrica, 1982, *Hozmadia* cf. *reticulata* Dumitrica, Kozur & Mostler, 1980, *Hozmadia* aff. *pyramidalis* Gorican and an undescribed form of *Poulpus*. This assemblage is considered to be of early Ladinian age.

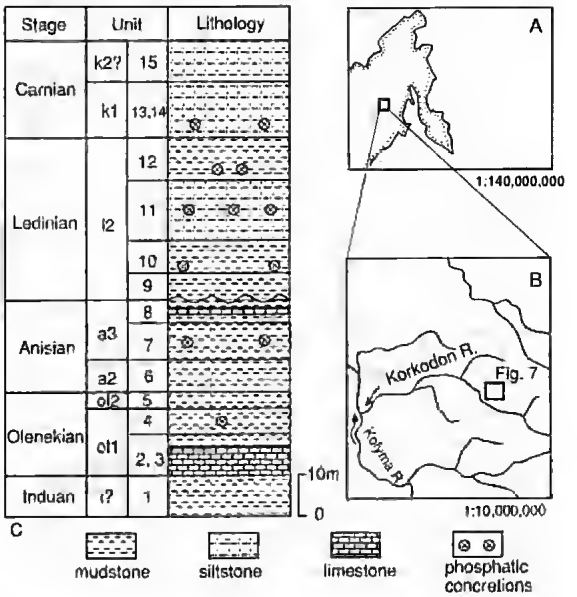


FIG. 6. — Geographic location (**A**, **B**) and stratigraphic column (**C**) for the Triassic section at Zhilny Creek, left bank, of Dzugadzak River (Omolon Massif, northeastern Siberia). Location map B showing the studied section (squared area, Fig. 7). Symbols on the left side of the stratigraphic column are: (1) stage and substage: **i?**, probably Induan, **ol1**, early Olenekian; **ot2**, late Olenekian; **a2**, middle Anisian; **a3**, late Anisian; **l2**, late Ladinian, **k1**, early Carnian; **k2?**, probably middle Carnian; (2) number of stratigraphic units as described herein.

The first appearance of *Capnuchosphaera* including *C. colemani* Blome, 1983, is recorded in the middle part of Unit 3. Numerous undescribed spumellarians belonging to the genera *Capnuchosphaera* De Wever, 1979, *Dumitricasphaera* Kozur & Mostler, 1979, *Karnospongella* Kozur & Mostler, 1981, *Pantanellium* Pessagno, 1977, *Sarla* Pessagno, 1979, *Welirella* Dumitrica, Kozur & Mostler, 1980, *Xenorum* Blome, 1984 are also present in this unit, and a Late Triassic age is inferred.

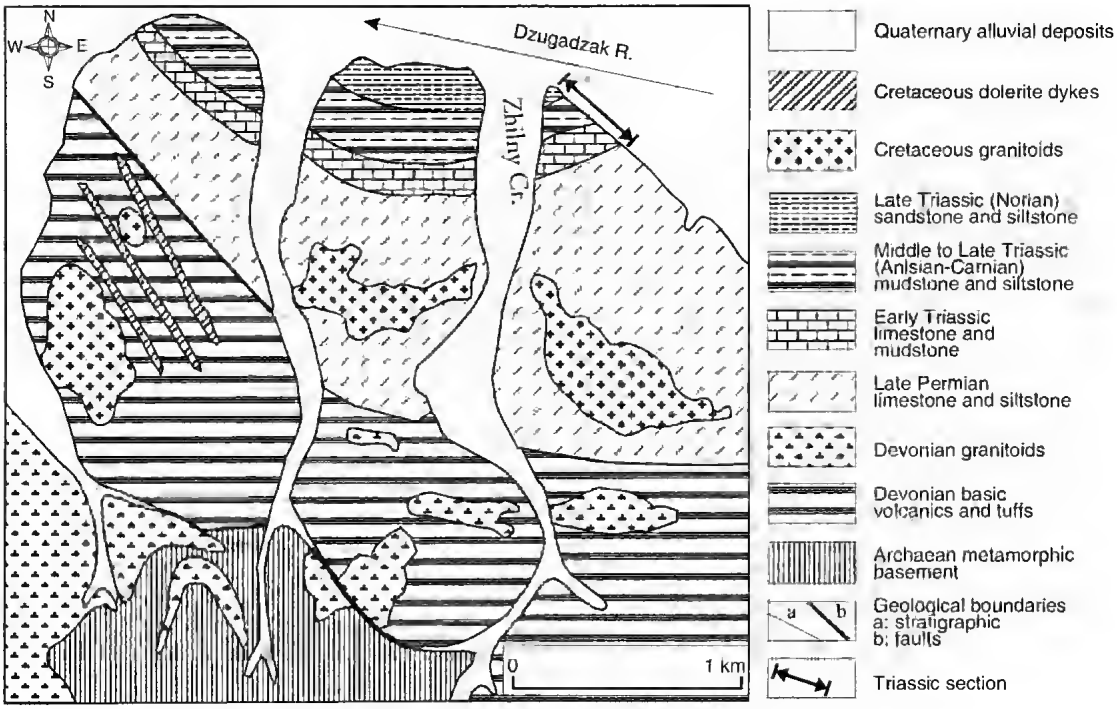


FIG. 7. — Geological map of the study area, left bank of Dzugadzak River.

CAPLES TERRANE, BULL CREEK, OTAGO

An additional fossil locality, H45/f074 (= field No. YABC-26; grid reference H45/884437) lies 500-600 m south of the mouth of Bull Creek on the Otago coast, southeast of Milton, South Island, New Zealand.

The locality is within Caples Terrane (Fig. 2). Some workers consider the Caples Terrane to be the southern extension of the Waipapa Terrane based on spatial relations and tectonic reconstructions of basement terranes (Spörli 1978). Radiolarians of Triassic and possible Middle-Late Jurassic ages have been reported from the "Chrystalls Beach Complex" along this section of the Otago Coast (Hada *et al.* 1988). Detailed examination (by Y. Aita) of radiolarians from phosphatic nodules in argillite from the Tuapeka Group exposed at Bull Creek have established that the faunas are of Middle Triassic age and that there are no Jurassic faunas. The Tuapeka Group rocks are best exposed on the South Otago coast between Chrystalls Beach and Taieri Mouth and are characterised by non-schistose sandstone and argillite with minor chert and phosphatic concretions. Roser *et al.* (1993), from trace element analysis, showed that the eastern Tuapeka Group rocks on the Otago coast display active continental margin felsic provenance, contain more of Torlesse-like sandstones and less mafic sandstone. On the other hand, Adams & Graham (1997) analysed Rb-Sr whole-rock isochrons and K-Ar whole rock ages of metagreywacke sequences in the Torlesse and Caples Terranes. According to their data, Bull Creek samples have an initial $^{87}Sr/^{86}Sr$ isotopic ratio of 0.70568 suggesting a provenance of "uncertain" terrane affinity corresponding to the "Waipapa-type" zone, but different from true Caples and Torlesse-type zones (Adams & Graham 1997). Thus geochronological and geologic data from Bull Creek samples show a similarity between Caples and Waipapa Terrane rocks.

RADIOLARIAN CORRELATION AND FAUNAL AFFINITY

The radiolarian fauna from the basal part of the Mahinepua Section, Waipapa Terrane, is remar-

kably similar to the early Ladinian assemblages from Bull Creek. Early Ladinian species in common to both Mahinepua and Bull Creek faunas include *Silicarmiger costatus costatus* Dumittica, Kozur & Mostler, *Parentactinia inerme* Dumitrica, *P. pugnax* Dumitrica, and *Spongopallium contortum* Dumitrica, Kozur & Mostler (Table 1). Recent work by Black (1994) suggests that the rocks in the type area (Omahuta-Puketi in southwest Notthland) of the Waipapa Tettane, are different from other Waipapa rocks and may be a North Island extension or correlative of the Caples Tettane. However, radiolarian faunal similarities suggest that the notthern Waipapa Terrane has close paleobiogeographic affinities with the easternmost Caples Terrane.

In addition, both Mahinepua and Bull Creek faunas contain many species (Table 1) known from the early Ladinian (Fassanian) patt of the Buchenstein Limestone in the Southern Alps of Europe (Dumitrica, Kozur & Mostler 1980; Gorican & Buser 1990; Kozur & Mostler 1994; Kozur *et al.* 1996). The Recoaro Limestone, of typical Tethyan affinity (Vicentinian Alps, northetn Italy) is known to yield more than 250 radiolatian species (Lahm 1984; Baumgattnet *et al.* 1997). However, it includes no forms of the new genus *Glomeropyle* (Table 1), whereas Mahinepua and Bull Creek faunas include abundant specimens and a number of forms of the new genus *Glomeropyle* (described herein). This genus may be restricted to high latitude affinity. The common occurrence of this genus, including especially *G. grantmackiei* n. sp. and *G.* (?) *galagala* n. sp. is characteristic of the early Ladinian Bull Creek fauna of the Caples Terrane, South Island. Undesctibed species of the genera *Poulpus* De Wever, 1979, *Hozmadia* Dumitrica, Kozur & Mostler, 1980, and *Plafkerium* Pessagno, 1979, are also present. The presence of simple multicyrtoids and the absence of the genus *Ladinocampe* Kozur, 1984 may characterize the Southern Hemisphete high latitude fauna in terms of paleobiogeographic affinity.

TRIASSIC RADIOLARIA IN SIBERIA

DZUGADZAK RIVER SECTION, OMOLON MASSIF

Radiolaria are present in the Dzugadzak Section of the Omolon Massif (northeastern Siberia). The Omolon Massif is regarded as a microcontinent with Pre-Cambrian metamorphic basement and a sedimentary cover of Paleozoic and Mesozoic age (Fig. 7). Ttiassic rocks in this region were deposited in oceanic conditions as hemipelagites. They are represented predominantly by claystones and mudstones with rare limestones and contain ammonoids, pseudoplanktonic bivalves, fotaminifers and radiolarians. Benthic fossils are relatively rare (Dagys *et al.* 1979; Egorov *et al.* 1987; Dagys *et al.* 1991; Dagys & Konstantinov 1995; Egorov & Bragin 1995).

The Triassic section is located on the left bank of Dzugadzak Rivet in its middle reaches. The following units ate exposed as follows (Figs 6, 7):

1a. Lower Triassic, Induan Stage (?)

Unit 1. Pale-grey claystones with poorly preset-ved brachiopods ..... 10 m.

1b. Lower Triassic, Lower Olenekian

Unit 2. Pale-grey bituminous platy and massive limestone with rareintercalations of grey mudstone ..... 7 m.

Unit 3. Grey, dark-grey and brownish-grey mudstone with intercalations (0.1 m) of grey limestone and brownish-grey claystone ..... 3 m.

Unit 4. Grey and dark-grey thin-bedded mudstone with intercalations (0.1-0.2 m) of black caustobiolithic shale with rare phosphotitic concretions containing poorly preserved Radiolaria ..... 6.5 m.

Units 2-4 are characterized by conodonts and bivalves confirming the presence of the early Olenekian: *hedenstroemi* and *tardus* zones.

1c. Upper Olenekian Stage

Unit 5. Dark-grey mudstone with *Claraia aranea* Tozer ..... 4 m.

2a. Middle Triassic, Middle Anisian

Unit 6. Dark-grey and black thin-bedded mud-

stone with ammonoid *Czekanowskites decipiens* (Mojsisovics). Lower contact of this bed erosional with a stratigraphic gap representing early Anisian time ..... 8 m.

2b. Middle Triassic, Upper Anisian

Unit 7. Dark-grey and black mudstone with numerous phosphoritic concretions, with the ammonoid *Amphipopanoceras dzenginense* Archipov and radiolarians *Triassothamnulus* (?) sp., *Entactinia* sp., *Pseudostylosphaera* (?) sp. ex gr. *P. fragilis* (Bragin, 1991), *P.* (?) sp., Spongodiscoidea (?) gen. indet., *Spongopallium* (?) sp., *Stauracontium* (?) sp., *Triassocampe* (?) sp. .. 9 m.

Unit 8. Dark-grey and black mudstone and siltstone with phosphoritic concretions and beds of grey fine sandstone, black caustobiolithic shale and brownish-grey bituminous limestone with the ammonoid *Parafrechites sublaqueatus* (Bytschkov, 1968) ..... 8 m.

2c. Ladinian

Unit 9. Black thin-bedded mudstone interbedded with grey, yellow and white claystone and dark-grey bituminous limestone with *Daonella prima* Kiparisova, 1937 ..... 5.5 m.

Unit 10. Dark-grey and black mudsrone and caustobiolitic shale with numerous phosphoritic concretions containing the ammonites *Arctoptychites omolojensis* Archipov, 1974 (lower 2.5 m), *Arctogymnites* cf. *speciori* Archipov, 1974, *Indigirophyllites oimekonensis* Popov, 1946 (5-5.5 m above base), algae *Tasmanites* sp., and Radiolaria: *Archaeocenosphaera* sp., *Entactinia* sp., *Ferresium* (?) sp., *Hindeosphaera* (?) sp., *Hozmadia* (?) sp., *Laxtorum* (?) sp., *Pachus* (?) sp., *Parentactinia pugnax* Dumitrica, *P.* cf. *inerme* Dumitrica, 1978, *Praenanina* sp., *Poulpus* sp., *Glomeropyle boreale* n. sp., *Silicarmiger costatus costatus* Dumitrica, Kozur & Mostler, 1980, *S.* cf. *latus* Kozur & Mostler, 1994, Spongodiscoidea gen. & sp. indet., *Spongopallium* aff. *koppi* (Lahm, 1984), *Stauracontium* (?) sp. ....6.5 m.

Unit 11. Black platy siltstone interbedded with yellow and white claystone, with rare phosphoritic concretions containing cephalopods *Arctoptychites* sp., *Indigirophyllites* sp., *Gryponautilus* sp. ex gr. *G. kegalensis* Sobolev, 1989 (1-1.2 m above base), *Nathorstites* sp. cf. *N. mclearni* Tozer, 1961, *Aristoptychites kolymensis* Kiparisova, 1961 (13.3 m above base) ..... 15 m.

Unit 12. Black thin-laminated mudstone with abundant phosphoritic concretions containing cephalopods: *Nathorstites mclearni* Tozer, *Aristoptychites kolymensis* Kiparisova, 1961 (1-2 m above base), *Sphaerocladiscites omolojensis* Bytschkov, 1968, *Indigirophyllites oimekonensis* Popov, *Nathorstites mcconnelli* (Whiteaves, 1889), *Simuplicorhynchia kegalensis* Dagys, 1965 (2.8-9.7 m above base), *Nathorstites lindstroemi* (Boehm, 1903), *Sphaerocladiscites omolojensis* Bytschkov (9.7-10.3 m above base), and Radiolaria: *Archaeocenosphaera* sp., *Pseudostylosphaera* sp., *Ferresium* (?) sp. ..... 10.5 m.

Unit 13. Black mudstone with abundant phosphoritic concretions with cephalopods *Nathorstites lindstroemi* Bohm, *Sphaerocladiscites omolojensis* Bytschkov (1.3-2.3 m above base), *Proclydonautilus aniamensis* (Shimansky, 1957) (4.1-6 m above base) ..... 11.6 m.

3. Late Triassic, Carnian

Unit 14. Dark-grey bituminous siltstone with abundant phosphoritic concretions with *Discophyllites* sp., *Stolleyites* cf. *tenuis* (Stolley, 1911), *Proclydonautilus aniamensis* (Shimansky), *Cenoceras boreale* Dagys & Sobolev, 1989 (0-0.3 m above base), *Proclydonautilus aniamensis* (Shimansky), *Pennospiriferina popovi* Dagys, 1965, *Pennospiriferina* (*Dentospiriferina*) *costata* Dagys, 1965, *P.* (*D.*) *pepeliaevi* Dagys, 1965 (1.1-3 m above base), *Halorhynchia tibetica* (Bittner, 1899) (4.5 m above base), and Radiolaria: *Pseudostylosphaera* sp., *Ferresium* sp. ..... 2 m.

Unit 15. Black platy siltstone with rare phosphoritic concretions and macrofossils: *Discophyllites taimyrensis* Popov, 1961, *Cenoceras boreale* Dagys & Sobolev, *Pennospiriferina* (*Dentospiriferina*) *costata* Dagys, *Planirhynchia yakutica* Dagys, 1965 (4.5-4.9 m above base) ..... 10 m.

Unit 16. Dark-grey massive and platy bioturbated siltstone with rare carbonate concretions containing *Discophyllites taimyrensis* Popov, and *Pennospiriferina* (*Dentospiriferina*) *costata* Dagys (5.3 m above base) ..... 8 m.

Unit 10 of this section contains the most diverse radiolarian assemblage including *Glomeropyle boreale* n. sp. and ammonoids which are common in northeastern Siberia, but not present in the low-latitude regions. This sequence was originally interpreted as early Ladinian (Dagys *et al.* 1979) but has been redetermined as the lower part of the late Ladinian (Dagys *et al.* 1991; Dagys & Konstantinov 1995). This conclusion was based on ammonoid data. However, radiolarian faunas have closer affinity with early Ladinian assemblages, based on the presence of such taxa as *Parentactinia pugnax* Dumitrica, *P.* cf. *inerme* Dumitrica, *Silicarmiger costatus costatus* Dumitrica, Kozur & Mostler, *S.* cf. *latus* Kozur & Mostler, *Spongopallium* aff. *koppi* (Lahm).
The variance of these two age interpretations require further research.
The age ranges of the key radiolarian taxa may be longer than presently understood and there is as yet poor correlation between ammonoid zones of high- and low-paleolatitude Ladinian sections.

CONCLUSIONS

Radiolarian faunas of Middle Triassic age from New Zealand and northeastern Siberia have been documented. They are characterized by abundant occurrences of non-Tethyan species including seven new species of *Glomeropyle* n. gen. (described herein). Although the fauna includes many species known from the European Tethyan sequences, the presence of *Glomeropyle* n. gen. is only known from southern and northern high latitudes during Middle Triassic time. In terms of Triassic paleobiogeography these radiolarian faunas appear to reflect a bipolar latitudinal pattern. Further examination of New Zealand and Siberian radiolarian faunas are required in order to esrablish Boreal and Austral faunal differentiation from Tethyan forms.

In New Zealand, the Mahinepua early Ladinian fauna in the Waipapa Terrane has a non-Tethyan affinity and is similar to that in the Caples Terrane. Furthermore, the Mahinepua Section offers great potential for establishment of a standard radiolarian biostratigraphy for Middle and Late Triassic successions that accumulated in southern high latitudes along the margin of Gondwanaland.

SYSTEMATIC PALEONTOLOGY

Type specimens of species authored by Aita are deposited at the Geology Department, Utsunomiya University (UTU), and of species authored by Bragin are deposited at the Geological Institute (GIN), Russian Academy of Sciences.

Suborder SPUMELLARIA Ehrenberg, 1875

Glomeropyle Aita & Bragin, n. gen.

TYPE SPECIES. — *Glomeropyle aurora* Aita n. sp.

ETYMOLOGY. — Latin, *glomero-* form into a ball; Greek *pyle-* gate, orifice, opening.

OCCURRENCE. — Middle Triassic, Anisian to Ladinian. Waipapa Terrane, North Island and Caples Terrane, South Island, New Zealand. Omolon Massif, northeastern Siberia.

DIAGNOSIS. — Shell of variable small to large size, subspherical, with open subcircular aperture and pylome, with or without primary spines; wall very thick, multi-layered, with internal cavity, with or without internal spicule, without medullary shells.

REMARKS

Glomeropyle n. gen. differs from the Tertiary *Prunopyle* Dreyer, 1889, emend Kozlova *in* Kozlova & Gorbovetz, 1966 by having a heavy thick-walled shell without medullary shells. It differs from *Sphaeropyle* Dreyer, 1889 by having a less spherical outer shell with pores irregularly arranged, and variable in size, and without medullary shells.
Although there are a number of species known from the Middle Triassic of New Zealand and

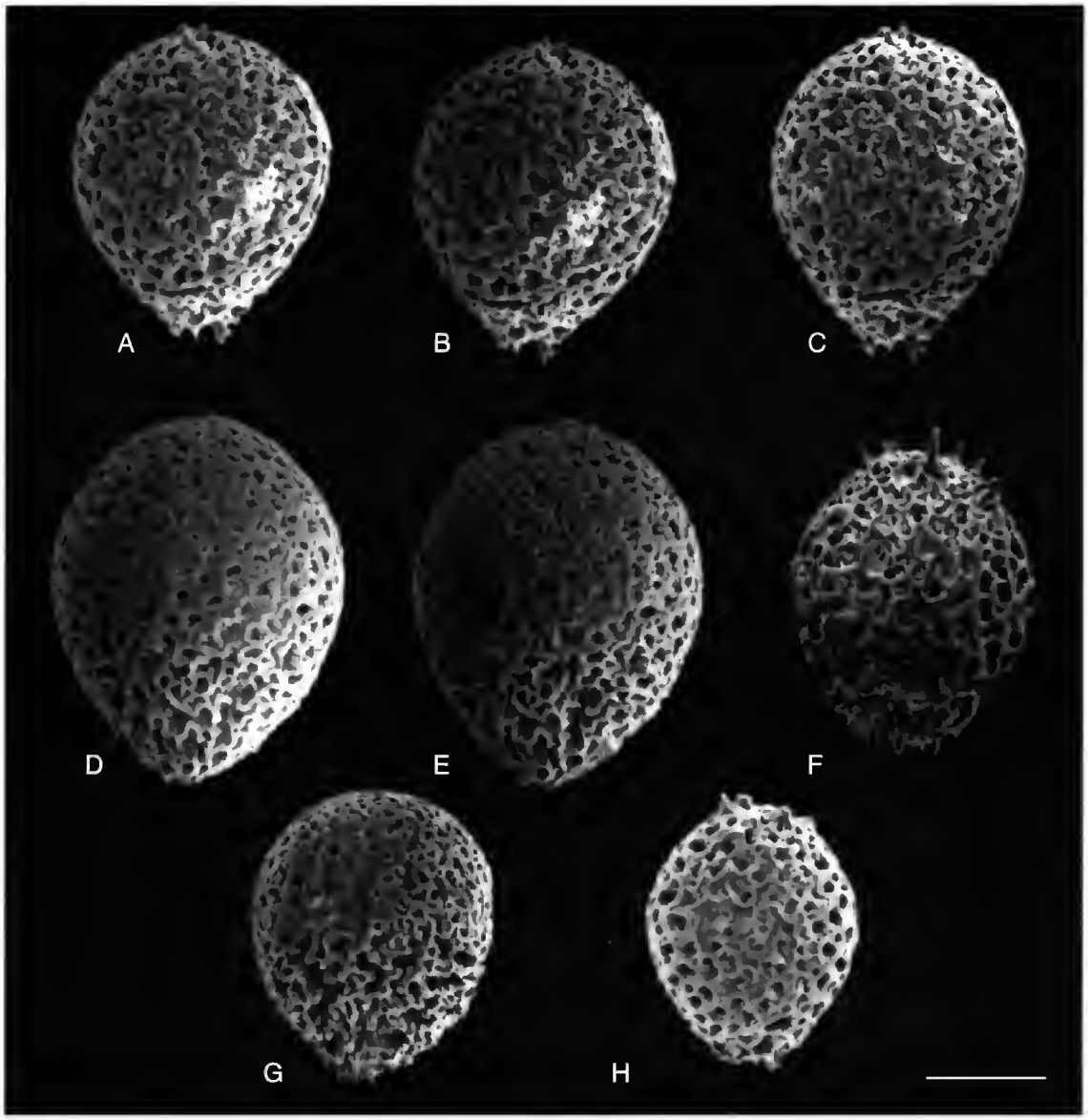


FIG. 8. — *Glomeropyle aurora* Aita, n. sp.; **A-C**, holotype (photo Nos 31101, 31102 & 31107); **A**, **B**, stereograph, **C**, lateral view; **D**, **E**, paratype (photo Nos 31123, 31125), stereograph; **F**, paratype (photo No. 31106); **G**, **H**, photo Nos 31109, 31110. Sample MAH-3.5, Unit 2, Mahinepua Peninsula, North Island, New Zealand. Scale bar: 100 µm.

Russia, however, no record of forms resembling any species of *Glomeropyle* n. gen. has been found from Middle Triassic sequences in the Europe, Japan, Southeast Asia or North America. Thus, this genus appears to be restricted to northern and southern high latitude areas, suggesting a bipolar biogeographic distribution.

Glomeropyle aurora Aita, n. sp.
(Fig. 8A-H)

TYPE MATERIAL. — Holotype: UTU101 (Fig. 8A-C). Paratypes: UTU102 (Fig. 8D, E), UTU103 (Fig. 8F).

TYPE LOCALITY. — All specimens from sample PO4/f103 (= MAH-3.5), Mahinepua Peninsula.

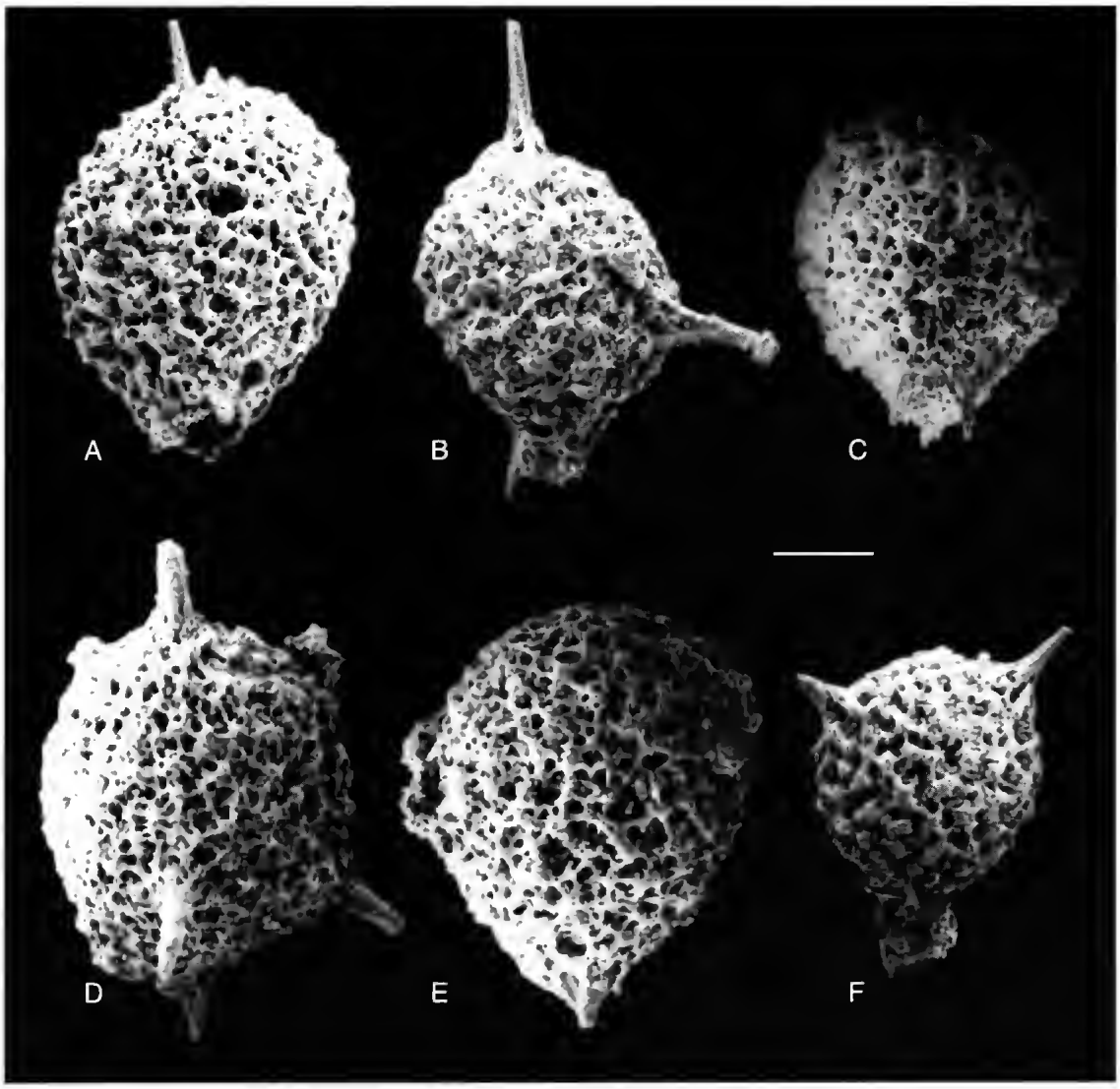


FIG. 9. — *Glomeropyle boreale* Bragin, n. sp.; **A**, holotype; **B-F**, paratypes. Northeastern Siberia, Omolon Massif, Dzugadzak River, Middle Triassic, Ladinian, Unit 10. Scale bar: 100 µm.

AGE. — Middle Triassic (Anisian to early Ladinian).

ETYMOLOGY. — Latin, *aurora*, dawn, morning.

OCCURRENCE. — Lower green argillite (sample MAH-3.5), Mahinepua Peninsula, Whangaroa area, Waipapa Terrane, North Island, New Zealand.

MEASUREMENTS. — Maximum width: 180-250 µm, height: 200-305 µm, thickness of shell wall: 10-15 (max. 20) µm.

DESCRIPTION

Relatively small, ovoidal shell with a few spines or clusters of short spines at one pole and with a short pylome at the other pole. Cortical shell usually thin-walled; upper part hemispherical, lower half part tapering, inverted conical with an aperture. Pores subcircular to irregular in shape, with or without pore frames. Pylome less developed, with a few short spines. Aperture narrow,

two to three times as wide as thickness of shell wall. No medullary shells recognized.

REMARKS
This species differs from *Glomeropyle poinui* Aita n. sp. in its smaller size and thinner shell, and by having a few spines or clusters of short spines at one pole.

Glomeropyle boreale Bragin, n. sp.
(Fig. 9A-F)

Pylentonemidae (?) gen. indet. – Egorov & Bragin 1995, fig. 2 (10-12).

TYPE MATERIAL. — Holoype GIN No. 7438-89-1 (Fig. 9A).

TYPE LOCALITY. — Omolon Massif, Dzugadzak River.

AGE. — Middle Triassic (Ladinian).

ETYMOLOGY. — Greek, *boreios*, god of the north wind.

OCCURRENCE. — Middle Triassic, Ladinian. Omolon Massif, northeastern Siberia.

MEASUREMENTS. — Maximum width of shell: 230-330 µm, height with pylome tube: 310-385 µm, diameter of aperture: 55-75 µm, length of spines: 50-120 µm.

DESCRIPTION
Large subspherical or roughly ellipsoidal shell with well-developed subcircular aperture forming short pylome. Small short rod-like spines are present around aperture, three of them longer than others. Outer shell with two visible layers; outer layer with polygonal (trigonal to pentagonal) commonly irregular pore frames with apophyses and massive nodes at vertices. Inner layer with small irregular pore frames.
Shell wall very thick, inner cavity small, inner structure unclear. One or more primary spines present, each with triangular in cross-section proximally, rod-like distally. Sometimes primary spines are absent.

REMARKS
Glomeropyle boreale Bragin, n. sp. differs from *G. mahinepuaensis* Aita, n. sp. in having a rougher shell surface, and in its larger and more clearly defined polygonal pore frames with massive nodes at vertices.

Glomeropyle poinui Aita, n. sp.
(Fig. 10A-F)

TYPE MATERIAL. — Holotype: UTU104 (Fig. 10A, B). Paratypes: UTU105 (Fig. 10C, D), UTU106 (Fig. 10E).

TYPE LOCALITY. — All specimens from sample PO4/f103 (= MAH-3.5), Mahinepua Peninsula.

AGE. — Middle Triassic (early Ladinian).

ETYMOLOGY. — Maori, *poinui*, a large ball.

OCCURRENCE. — Lower green argillite (sample MAH-3.5), Mahinepua Peninsula, Whangaroa area, Waipapa Terrane, North Island, New Zealand.

MEASUREMENTS. — Maximum width: 265-310 µm, height: 310-355 µm, thickness of shell wall: 25-30 (max. 40) µm.

DESCRIPTION
Large spherical to subspherical shell with a short pylome. Cortical shell thick-walled with numerous subcircular to irregular small pores. Pores variable in size usually without distinct pore-frames, but rarely with polygonal pore-frames. Overall outline smooth, but area around pylome rough. Aperture narrow. No medullary shells recognized.

REMARKS
Glomeropyle poinui Aita n. sp. resembles *Glomeropyle aurora* Aita n. sp. in overall shape, but it is distinguished by its large size (> 265 µm in maximum width) and thicker shell wall commonly with smooth surface.

Glomeropyle* (?) *galagala Aita, n. sp.
(Fig. 11A-C)

TYPE MATERIAL. — Holotype: UTU107 (Fig. 11A, B).

TYPE LOCALITY. — Sample PO4/f103 (= MAH-3.5), Mahinepua Peninsula.

AGE. — Middle Triassic (early Ladinian).

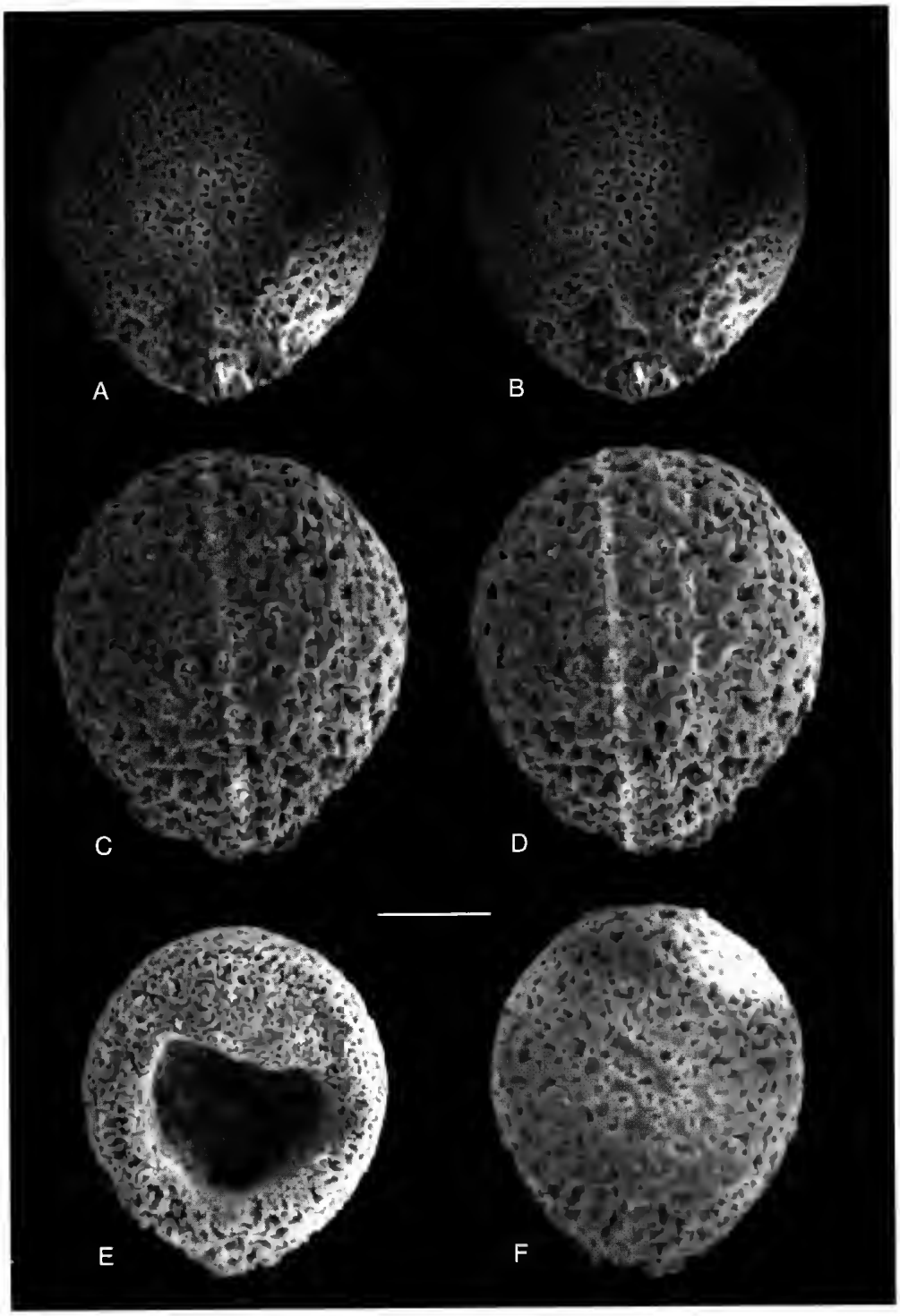


FIG. 10. — *Glomeropyle poinui* Aita, n. sp.; **A**, **B**, holotype, stereograph (photo Nos 31104, 31105); **C**, **D**, paratype stereograph (photo Nos 31126, 31127); **E**, paratype (photo No. 31128); **F**, photo No. 31135. Sample MAH-3.5, Unit 2, Mahinepua Peninsula, North Island, New Zealand. Scale bar: 100 µm.

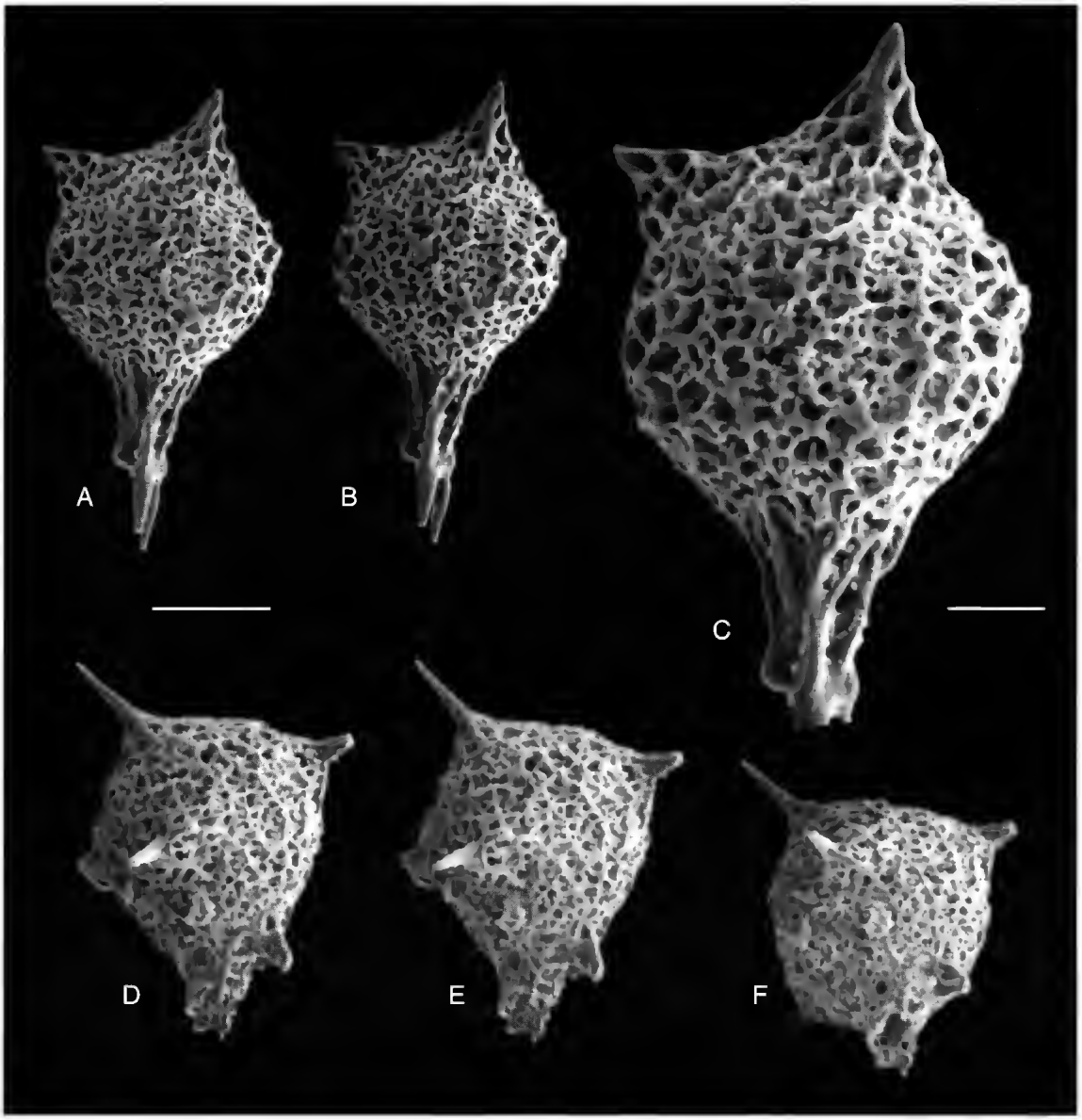


FIG. 11. — **A-C**, *Glomeropyle* (?) *galagala* Aita, n. sp.; **A**, **B**, holotype, stereograph (photo Nos 31075, 31076); **C**, close-up view, holotype (photo No. 31077); **D-F**, *Glomeropyle grantmackiei* Aita, n. sp.; holotype (photo Nos 31089, 31090, 31092); **D**, **E**, stereograph; **F**, oblique basal view. Sample MAH-3.5, Unit 2, Mahinepua Peninsula, North Island, New Zealand. Scale bars: A, B, D-F, 100 µm; C, 50 µm.

ETYMOLOGY. — Japanese, *galagala*, a rattle.

OCCURRENCE. — Lower green argillite (sample MAH-3.5), Mahinepua Peninsula, Whangaroa area, Waipapa Terrane, North Island; Bull Creek (sample YABC-26), Caples Terrane, South Island, New Zealand.

MEASUREMENTS. — Maximum width of shell: 210 µm (holotype 194 µm), height of shell: 220 µm (holotype 188 µm), length of spines: 70, 50 µm (holotype 62.5, 50 µm), length of pylome:100 µm (holotype 150 µm).

DESCRIPTION

Spherical shell with two conical spines at one

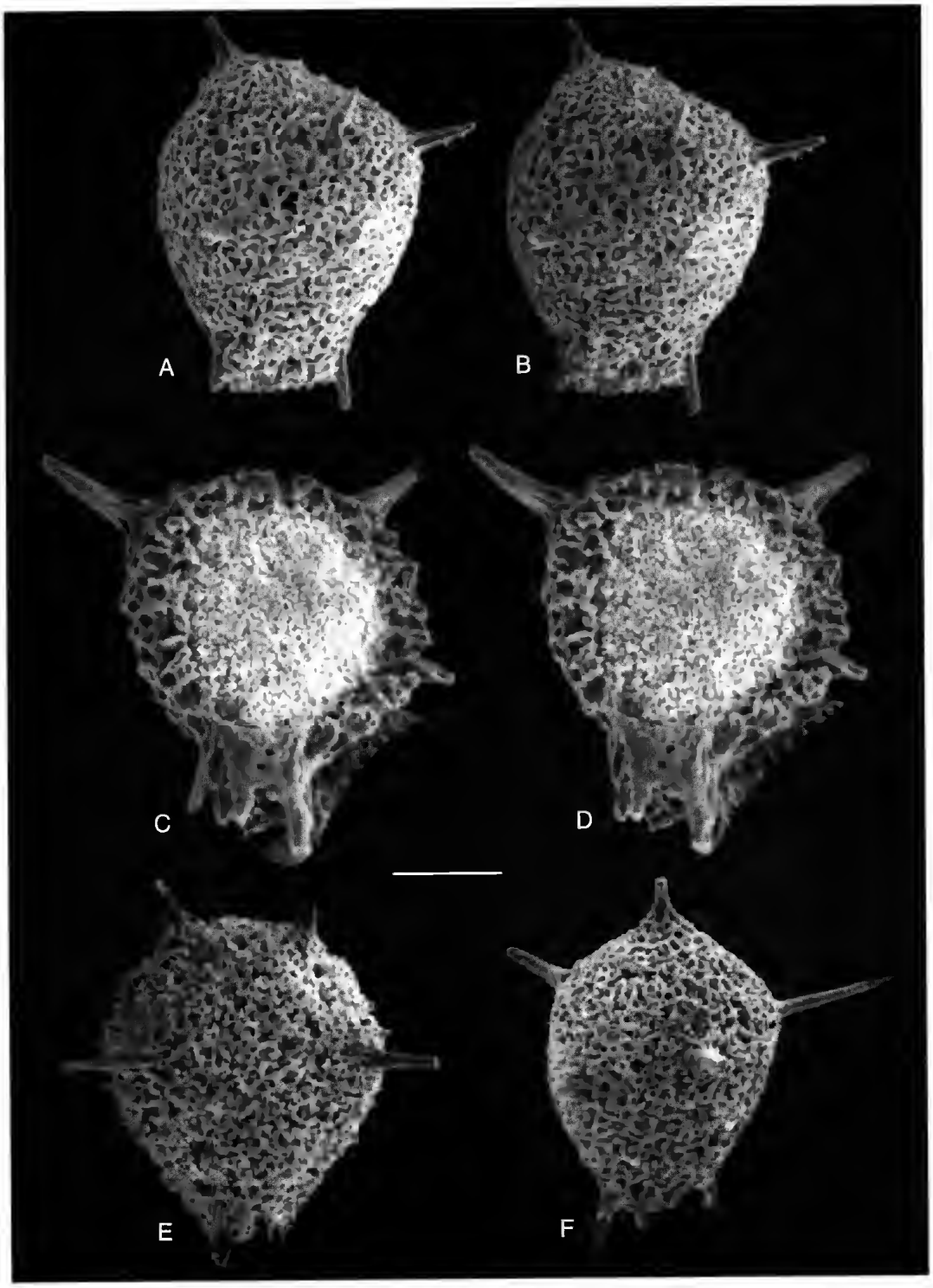


FIG. 12. — *Glomeropyle grantmackiei* Aita, n. sp.; **A**, **B**, paratype, stereograph (photo Nos 31066, 31067); **C**, **D**, stereograph (photo Nos 31098, 31097); **E**, (photo No. 31072); **F**, paratype (photo No. 31073). Sample YABC-26, Bull Creek, Caples Terrane, Otago, South Island. Scale bar: 100 µm.

end and a developed pylome at the other end. Cortical shell double layered with rough ridged surface; outer layer with triangular to polygonal coarse mesh consisting of interconnecting bars; inner layer fine meshed but unclear in detail. Two distinct conical spines forming angle of 60°. Angles between one pole and each spine asymmetric, 20° and 40°. Pylome well-developed, with long spines, sometimes forming a long perforate hollow tube. Usually two or three minute spines fused at ends, forming a rod-like stout spine.

REMARKS

This species is questionably assigned to the genus *Glomeropyle* Aita & Bragin, n. gen. because it has approximately spherical shell and has two distinct horn like spines.

Glomeropyle grantmackiei Aita, n. sp.
(Figs 11D-F, 12A-F)

TYPE MATERIAL. — Holotype: UTU108 (Fig. 11D-F). Paratypes: UTU109 (Fig. 12A, B), UTU110 (Fig. 12F).

TYPE LOCALITY. — Holotype: sample PO4/f103 (= MAH-3.5), Mahinepua Peninsula. Paratypes: sample H45/f074 (= field No. YABC-26), Bull Creek.

AGE. — Middle Triassic (early Ladinian).

ETYMOLOGY. — This species is named for Professor Jack A. Grant-Mackie, Department of Geology, The University of Auckland, in honour of his significant contribution to paleontology in New Zealand.

OCCURRENCE. — Rare in the lower green argillite (sample MAH-3.5), Mahinepua Peninsula, Whangaroa area, Waipapa Terrane, North Island; common to abundant in Bull Creek (sample YABC-26), Caples Terrane, South Island, New Zealand.

MEASUREMENTS. — Maximum width of shell: 200-345 µm, height of shell: 215-325 µm, length of pylome: 38-70 µm, width of aperture: 40-70 µm, thickness of shell: 40-60 µm, length of spines: 70-120 µm.

DESCRIPTION

Large hemispherical, thick-walled shell with a well-developed pylome. Cortical shell consisting of a thick outer layer with coarse spongy meshwork and a thin inner spongy layer. Pores numerous, irregular in shape, variable in size, closely spaced, separated by intervening bars. Rather long, stout, rod-like slender spines are sparsely distributed; four or five spines recognized on the visible side. Each spine three-bladed up to middle of basal portion and with grooves only at base. Aperture well-defined, medium-sized, forming a cylindrical to sometimes tubular pylome, with two to three descending spines.

REMARKS

Glomeropyle grantmackiei Aita n. sp. has a relatively broad morphological variation. It includes such morphotypes as those ornamented with ridged, and nodose surfaces on the inflated subspherical shell. Very heavy massive rod-like spines are developed on many specimens from the phosphatic nodule sample of Bull Creek, Caples Terrane.

Glomeropyle mahinepuaensis Aita, n. sp.
(Fig. 13A-J)

TYPE MATERIAL. — Holotype: UTU111 (Fig. 13A, B). Paratypes: UTU112 (Fig. 13D, E), UTU113 (Fig. 13H, I).

TYPE LOCALITY. — All specimens from sample PO4/f103 (= MAH-3.5), Mahinepua Peninsula.

AGE. — Middle Triassic (early Ladinian).

ETYMOLOGY. — This species is named for Mahinepua Peninsula, Whangaroa area, Northland, New Zealand, as the type locality.

OCCURRENCE. — Common in the lower green argillite (sample MAH-3.5), Mahinepua Peninsula, Whangaroa area, Waipapa Terrane, North Island, New Zealand.

MEASUREMENTS. — Maximum width of shell: 144-250 µm, height of shell: 138-280 µm, length of spines: 25-55 µm, length of pylome: 18-50 µm.

DESCRIPTION

Cortical shell pyriform with an opening at one end bearing a short pylome. Pores small, subcircular to subangular, irregularly arranged. Overall shell with rough surface of numerous small nodes at vortex of pore-frames. Slender, cylindri-

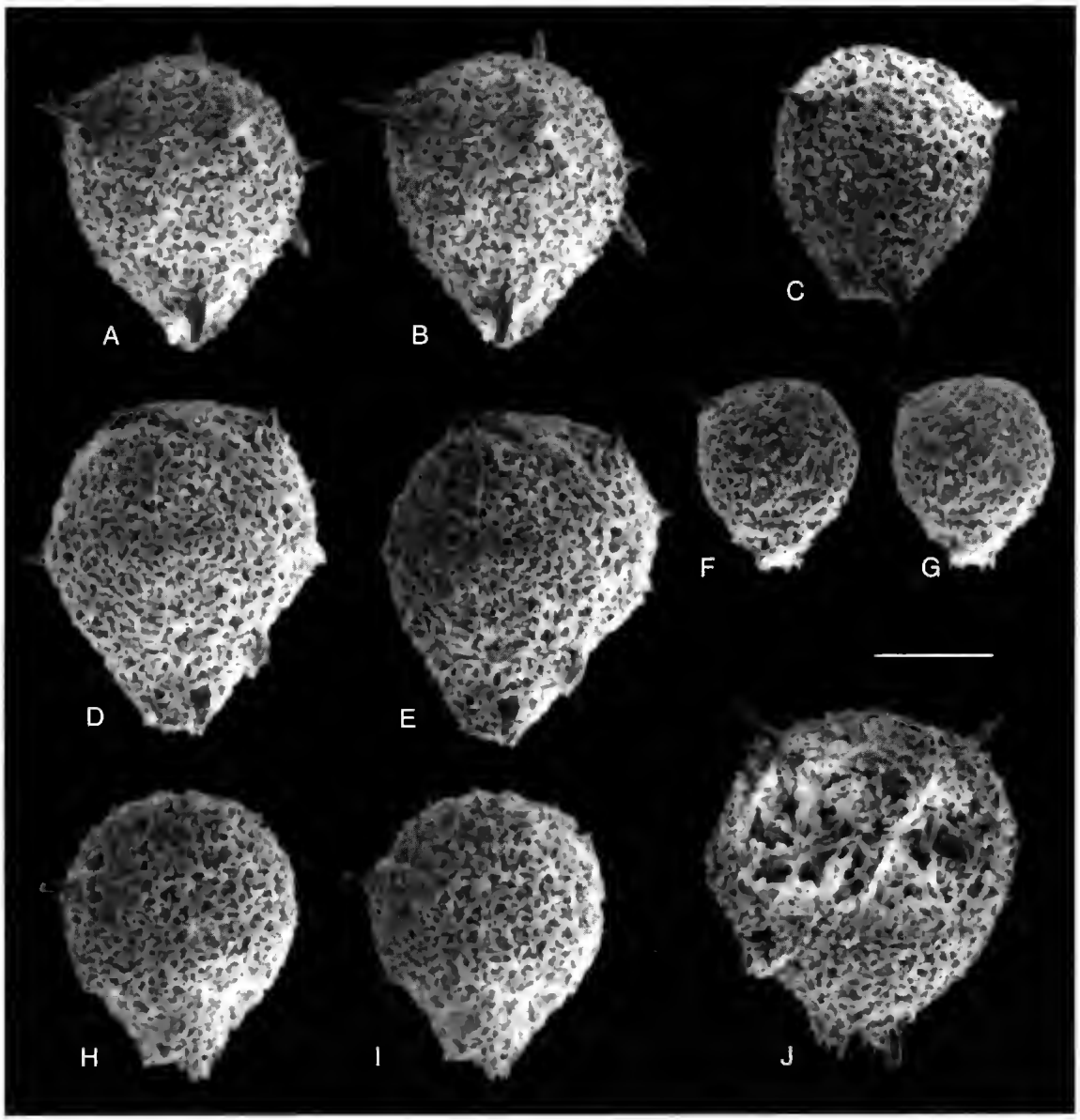
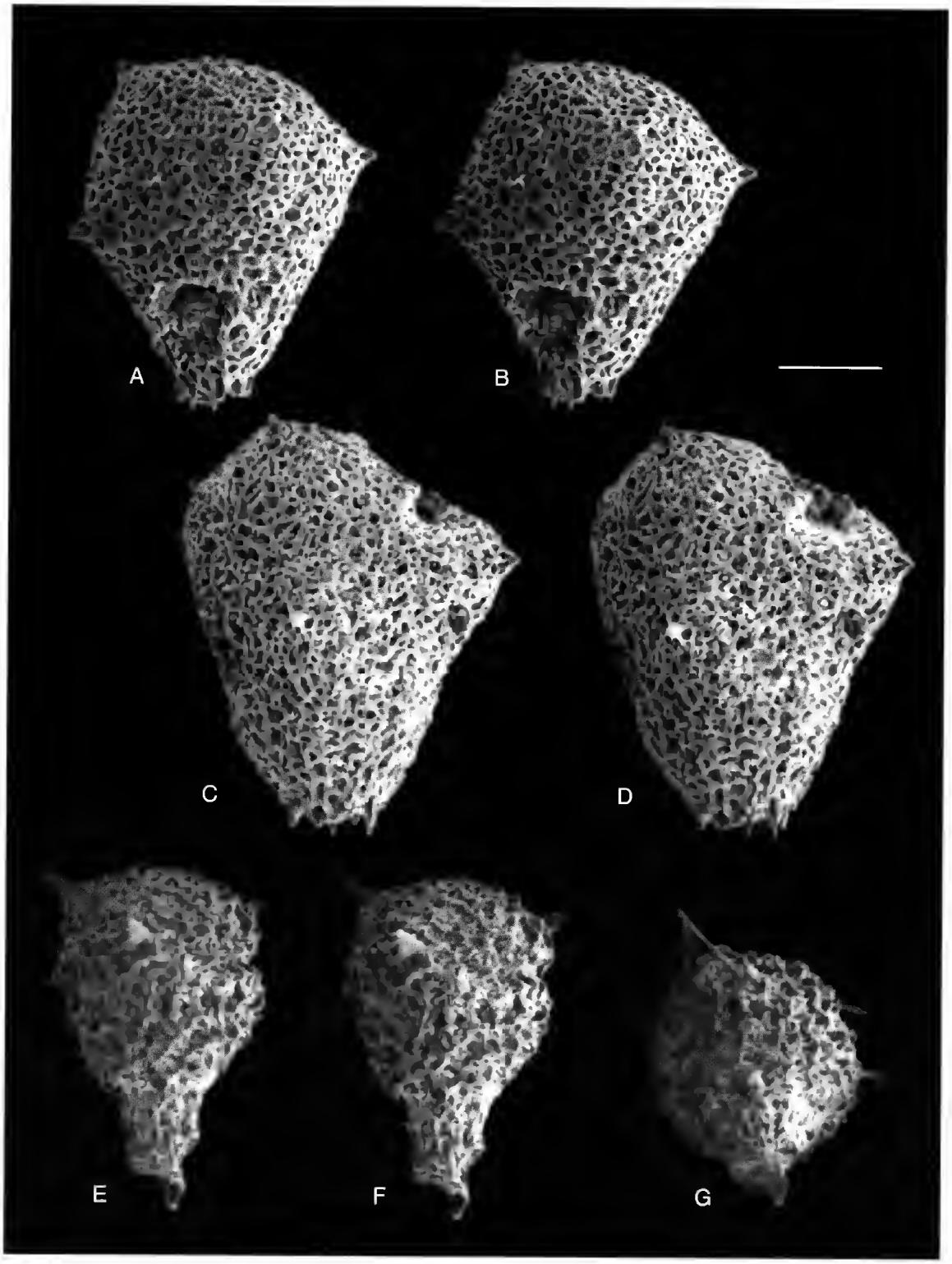


FIG. 13. — *Glomeropyle mahinepuaensis* Aita, n. sp. ; **A**, **B**, holotype, stereograph (photo Nos 31111, 31112); **C**, photo No. 31119; **D**, **E**, paratype, stereograph (photo Nos 31113, 31114); **F**, **G**, paratype, stereograph (photo Nos 31129, 31130); **H**, **I**, paratype, stereograph (photo Nos 31116, 31115); **J**, photo No. 31117. Sample MAH-3.5, Unit 2, Mahinepua Peninsula, North Island, New Zealand. Scale bar: 100 µm.

cal, short spines widely spaced and developed from the shell surface. Between two and five spines rise upward and at least two spines extend downwards. Pylome well-developed with a short stout descending spine and many minute spines. No medullary shell recognized.

REMARKS

Glomeropyle mahinepuaensis Aita, n. sp. resembles *Glomeropyle grantmackiei* Aita, n. sp. in overall shape, but is distinguished from the latter in having a smaller shell, thinner shell wall and shorter, more slender spines. This species differs


A
B
C
D
E
F
G

from *Glomeropyle aurora* Aita, n. sp. by having rather rough, pointed nodes on the shell surface and more frequently arranged short spines.

Glomeropyle waipapaensis Aita, n. sp. (Fig. 14A-D)

TYPE MATERIAL. — Holotype: UTU114 (Fig. 14A, B).

TYPE LOCALITY. — Sample PO4/f103 (= MAH-3.5), Mahinepua Peninsula.

AGE. — Middle Triassic (early Ladinian).

ETYMOLOGY. — This species is named for the Waipapa Terrane, a typical accretionary complex of Triassic to Jurassic age, including spilite, chert, green argillite, sandstone, and minor limestone, North Island, New Zealand.

OCCURRENCE. — Lower green argillite (sample MAH-3.5), Mahinepua Peninsula, Whangaroa area, Waipapa Terrane, North Island, New Zealand.

MEASUREMENTS. — Holotype: maximum width of shell: 269 µm, height of shell: 313 µm, length of spines: 25 µm, length of pylome: 31 µm.

DESCRIPTION

Large thick-walled shell, upper half dome-shaped and lower funnel-shaped, with rather ridged surface. Very short, pointed spines are sparsely distributed at apex between four facets; four spines recognized on the visible side. Shell probably double-layered; inner layer is unclear, but intervening bars are visible. Pores closely-spaced, circular to subcircular, variable in size, irregularly arranged with rectangular, pentagonal to hexagonal pore-frames. Ridges or small knobs are developed from apex of pore-frames. Pylome well-developed, with teeth-like spines.

REMARKS

This species resembles *Glomeropyle grantmackiei* Aita, n. sp. in having a similar shape and size. However, it differs from the latter in having more circular to subcircular pores on the shell, is less spinose, and has very short pointed spines.

FIG. 14. — **A-D**, *Glomeropyle waipapaensis* Aita, n. sp.; **A**, **B**, holotype, stereograph (photo Nos 31079, 310785); **C**, **D**, stereograph (photo Nos 31081, 31084). **E-G**, *Glomeropyle* cf. *grantmackiei* Aita, n. sp. (photo Nos 31087, 31088, 31091); **E**, **F**, stereograph, **G**, basal view. Sample MAH-3.5, Unit 2, Mahinepua Peninsula, North Island, New Zealand. Scale bar: 100 µm.

Acknowledgements

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Correlation of the early Albian-late Turonian radiolarian biozonation with planktonic and agglutinated foraminifera zonations in the Pieniny Klippen Belt (Polish Carpathians)

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ABSTRACT
Marine pelagic deposits of the lower Albian to upper Turonian interval in the Polish part of the Pieniny Klippen Belt are relatively rich in radiolarian fauna as well as in planktonic and agglutinated foraminifera. The proposed radiolarian zones (*Holocryptocanium barbui*, *Hemicryptocapsa prepolyhedra* and *Hemicryptocapsa polyhedra*) have been correlated with planktonic foraminifera biozonation (from *Ticinella primula* to *Dicarinella primitiva* zones), and with agglutinated foraminifera biozonation (from *Haplophragmoides nonioninoides* to *Uvigerinammina* ex gr. *jankoi* zones).

KEY WORDS
Cretaceous,
Radiolaria,
Foraminifera,
integrated biostratigraphy,
Pieniny Klippen Belt,
Carpathians.

RÉSUMÉ
Corrélation des biozones à radiolaires de l'Albien inférieur-Turonien supérieur avec celles à foraminifères planctoniques et agglutinés dans la région des klippes piénines (Carpathes polonaises).
Les dépôts marins pélagiques de l'Albien inférieur-Turonien supérieur de la zone des klippes piénines sont relativement riches en faune de radiolaires, ainsi que de foraminifères planctoniques et agglutinés. Les zones de radiolaires proposées (*Holocryptocanium barbui*, *Hemicryptocapsa prepolyhedra* et *Hemicryptocapsa polyhedra*) sont en correlation directe avec les biozones de foraminifères planctoniques (de la zone *Ticinella primula* à la zone *Dicarinella primitiva*) et celles des foraminifères agglutinés (de la zone *Haplophragmoides nonioninoides* à la zone *Uvigerinammina* ex gr. *jankoi*).

MOTS CLÉS
Crétacé,
Radiolaria,
Foraminifera,
biostratigraphie intégrée,
zone des klippes piénines,
Carpathes.

INTRODUCTION

Detailed micropalaeontological studies of marine pelagic Cretaceous deposits have been carried out in the Pieniny Klippen Belt during the last 15 years. A part of these concerned biostratigraphy, based on different groups of microfauna: foraminifera (Birkenmajer & Jednorowska 1987; Gasiński 1988; Kostka 1993; K. Bąk 1998), nannoplankton (Dudziak 1985), dinocysts (Jamiński 1990) and radiolaria (M. Bąk 1995; 1996a, b). However, only very few studies comprise an integrated biostratigraphy of these deposits (Birkenmajer *et al.* 1979; K. Bąk *et al.* 1995).

The Cretaceous deposits of the Pieniny Klippen Belt provide the best material for the integrated biostratigraphical studies in the whole Carpathians, because they represent pelagic and hemipelagic calcareous-marly facies, and contain abundant microfauna. These deposits have been formed in the Pieniny Klippen Basin (Birkenmajer 1977), a part of the Penninic Ocean-northern part of Western Tethys (Fourcade *et al.* 1993) (Fig. 1A). The sedimentation during Albian through Campanian took place under deep-water conditions, ar outer shelf through lower bathyal/abyssal depths, above or near CCD (Birkenmajer & Gasiński1992; K. Bąk 1995a, b). They crop out in a highly tectonically deformed zone, known as the Pieniny Klippen Belt, that separates the Inner from the Outer Carpathians (Fig. 1B, C).

The present authors propose here an integrated local biostratigraphy based on planktonic Foraminifera, agglutinated Foraminifera and Radiolaria for early Albian through late Turonian time span. The correlation is based on studies of microfauna from the same samples within the same sections. Foraminifera and Radiolaria are relatively abundant in the studied deposits.

GEOLOGICAL SETTING AND RADIOLARIAN HORIZONS

Twenty five sections located at Niedzica, Krościenko, Szczawnica, Jaworki, Sromowce, Dursztyn, Szaflary and Stare Bystre have been chosen for integrated micropalaeontological analyses. A detailed description of profiles, sample location, and lithology is given in papers by K. Bąk (1992, 1993, 1998) and M. Bąk (1995, 1996a, b, 1997). In 18 of these sections, radiolarian skeletons have been found together with foraminifera, and the best sections (15) were used here for correlation purposes (Figs 1, 2).

In the sections examined, the microfauna has been recovered from the deposits of the Kapuśnica and Jaworki formations. Lithological features, thickness and age of these lithostratigraphical units, distinguished by Birkenmajer (1977, 1987), and Birkenmajer & Jednorowska (1984) and presented below, concern only the studied sections.

Kapuśnica Formation

This formation is subdivided in two members, the Brodno Member and the Rudina Member, both represented in the sections investigated.

The Brodno Member. It has been identified only in the one section as a 40 cm thick layer of black marls, ? upper Aptian in age. The radiolarian fauna is present but very rare in these deposits.

The Rudina Member. (1-20 m thick; lower-upper Albian) It is represented by green-grey and black marls and marly shales with marly limestone intercalations, with red marls appearing in the upper part. Abundant and well-preserved radiolarian skeletons are present in green and black marls and marly shales.

Jaworki Formation

Deposits of the Jaworki Formation have been examined in sections belonging to all Klippen successions (Fig. 2).

The Brynczkowa Marl Member. (2-22 m thick; Vraconian-middle Cenomanian) It consists of green or grey-green marls with thin scarce red marl intercalation. Moderately to poorly preserved radiolaria are rare.

The Skalski Marl Member. (4-15 m thick; middle-upper Cenomanian) It consists of variegated marls, intercalated with green, red and grey marls. Except of the Altana Shale Bed, the radiolarians are present in this member but are rare and mostly poorly preserved.

The Altana Shale Bed. (0.4-3 m thick;

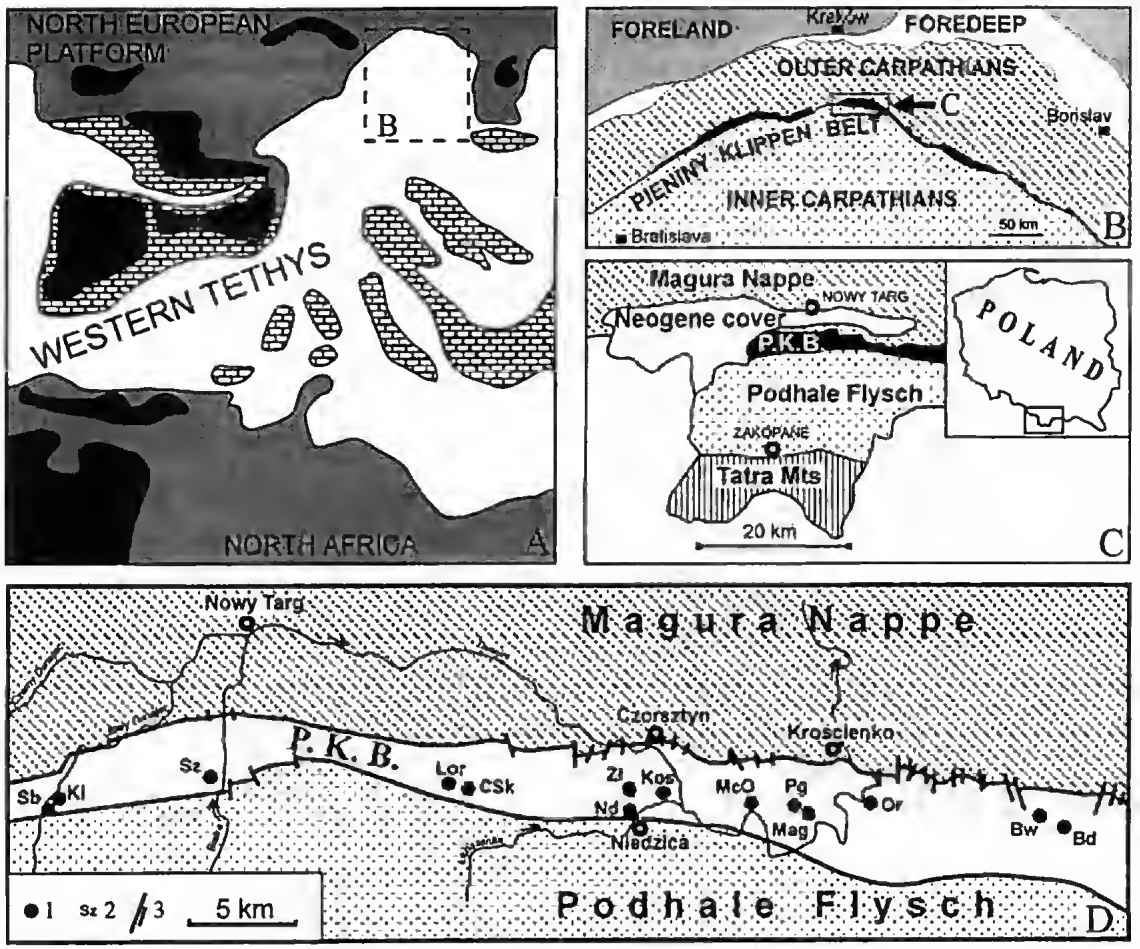

FIG. 1. — Location of the study area: **A**, in the Western Tethys (rectangle B) (map of late Cenomanian palaeoenvironments after Fourcade *et al*, 1993; simplified); **B**, **C**, in the Carpathians (Pieniny Klippen Belt in black); **D**, in the Pieniny Klippen Belt. Legend: **1**, investigated outcrops; **2**, symbols of outcrops; **3**, more important dislocations. List of outcrops (from west to east): **Sb**, Stare Bystre; **Kl**, Kietowy stream; **Sz**, Szaflary quarry, **Lor**, Lorencowe Klippes; **Csk**, Czerwona Skała; **Zl**, Zlobowy Creek; **Nd**, Niedziczanka stream; **Kos**, Kosarzyska Valley; **McO**, Macelowa-Osice; **Pg**, Podskalnia Góra Mt; **Mag**, Magierowa Klippe; **Or**, Orlica Hill; **Bw**, Bukowiny Valley; **Bd**, Bukowiny Hill.

Cenomanian/Turonian boundary) It consists of black-blue, greenish and black shales and marly shales. Radiolarians are abundant but low-diversified and poorly preserved. Their pyritized skeletons are mostly found within the Czorsztyn Succession deposits.

The Magierowa Marl Member. (9 m; Cenomanian/Turonian boundary) It is represented by shales, marly shales, marls, and thin-bedded marly limestone of grey to green colour with black alternations. Radiolarian fauna is abundant: well-preserved siliceous specimens are present in green and grey shales and marly shales. The radiolarians are also abundant in black shales but are often difficult to determine, because of Fe-oxide coating and pyritization.

The Trawne Member. (5 m; lower-middle Cenomanian) It consists of grey-green marls and shaly marls with sandstone intercalations. Radiolarian fauna is scarce: only a few poorly preserved specimens have been found.

The Snežnica Siltstone Member. (3-? 40 m;

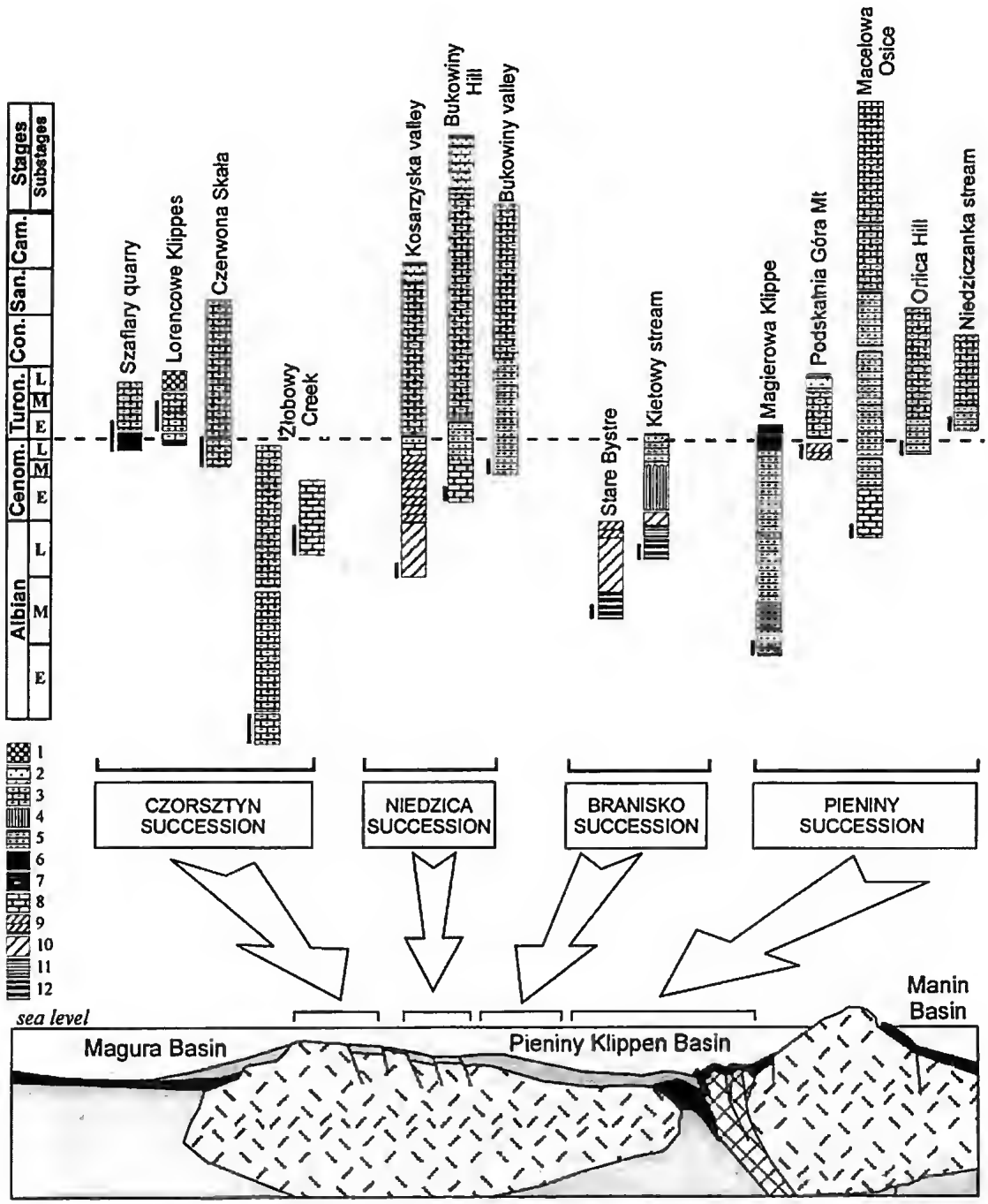

Fig. 2. — Lithological columns of the studied sections in relation to the age of deposits (dashed line corresponds to the Cenomanian/Turonian boundary) and their attribution to Klippen successions and sedimentary zones [Pieniny Klippen Basin reconstruction after Birkenmajer (1977)]. Lithological units investigated [lithostratigraphy after Birkenmajer (1977, 1987), Birkenmajer & Jednorowska (1984)]: **1**, Lorencowe Chert Bed; **2**, Osice Siltstone Member; **3**, Macelowa and Pustelnia Marl members; **4**, Trawne Member; **5**, Sneżnica Siltstone Member; **6**, Altana Shale Bed; **7**, Magierowa Member; **8**, Skalski Marl Member; **9**, Brynczkowa Marl Member; **10**, Rudina Member; **11**, Brodno Member; **12**, Pieniny Limestone Formation. Scale bars: 5 m, except of Branisko Succession sections, 1 m.

middle Cenomanian-middle Turonian) It is represented by alternating bright blue-grey and green shaly marls with thin-bedded siltstone and sandstone, and bright-green pelitic limestone intercalations. Radiolarians are rare in this member, but the upper Cenomanian deposits are enriched in well-preserved, pyritized radiolarian skeleton.

The Macelowa Marl Member. (15-70 m; lower Cenomanian-Santonian) It consists mostly of red marls and marly limestone with thin intercalations of greenish or bluish siltstones and sandstones which appear in its lower and upper parts. Poorly preserved and mainly calcified radiolarians are present in this member. They are diversified, especially those found in a horizon corresponding to the lower-middle Turonian.

The Pustelnia Marl Member. (6-45 m; middle Cenomanian-Santonian) It consists of pure brick-red, strongly tectonized marls without clastic intercalations. Radiolarian skeletons are very scarce, poorly preserved, and mainly calcified.

The Lorencowe Chert Bed. (3 m; upper Santonian-lower Campanian) It is represented by a two-meter-thick complex consisting of alternating variegated marls (mostly red) with thin intercalations of light-green limestone. Radiolarian skeletons are also scarce, poorly preserved, mostly calcified.

RADIOLARIAN ASSEMBLAGES

Seventy seven radiolarian species have been determined from the Cretaceous deposits ranging from lower Albian to Santonian of the Pieniny Klippen Belt: 20 genera and 53 species of Nassellaria, and 11 genera and 24 species of Spumellaria were recognised (M. Bąk 1997).

The assemblages, in all Klippen successions investigated, are dominated by cryptocephalic and cryptothoracic Nassellaria belonging to the genera *Holocryptocanium*, *Hemicryptocapsa*, *Cryptamphorella*, *Dorypyle*, *Hiscocapsa*, *Trisyringium* and *Squinabollum*. Multisegmented Nassellaria are also common being represented by the genera *Dictyomitra*, *Thanarla*, *Pseudodictyomitra*, *Stichomitra*, *Xitus*, *Obeliscoites* and *Torculum*. Spumellaria are less common; the most abundant are the specimens belonging to the families Actinommidae, Praeconocaryommidae, Xiphostylidae (genera *Staurosphaeretta* and *Triactoma*), and Dactyliosphaeridae (*Dactyliodiscus*, *Godia* and *Dactyliosphaera*). Other Spumellaria belong to the genera *Hexapyramis*, *Cavaspongia*, *Pseudoaulophacus*, *Patellula*, *Paronaella* and *Crucella*.

Within the Klippen successions investigated, the radiolarians are most abundant and diversified in the Czorsztyn Succession deposits (outer shelf-upper bathyal environment), becoming generally scarce in the deposits of the Pieniny Succession (lower barhyal environments, close to Calcium Compensation Depth).

The radiolarian specimens are most abundant and diverse in green and black marly shales, marls and limestones of the Kapuśnica and Pomiedznik formations, the Magierowa Member and the Altana Shale Bed of the Jaworki Formarion. They are scarce in red and variegated marls and shales of the Macelowa Marl, Brynczkowa Marl and the Skalski Marl members of the Jaworki Formation. This might be dependent on lithology and diagenesis factors responsible for preservation of siliceous microfossils; however, radiolarian faunas radiation and turnovers could be also taken into account. Both causes might reflect an ecological response of marine biota to global climate and sea level changes during mid-Cretaceous times.

Two great changes in the radiolarian assemblages have been recorded within the studied deposits:

1. Beginning of an important first radiation of Radiolaria occurred during the middle Albian (*Ticinella primula* foraminiferal zone, K. Bąk 1992) as many new species had their first appearance in the middle and the late Albian. The maximum of differentiation in the radiolarian assemblage is observed in the Vraconian deposits (*Rotalipora ticinensis* through the *Rotalipora appenninica-Planomalina buxtorfi* foraminiferal zones, K. Bąk 1998). Starting from the upper part of the *R. appenninica-P. buxtorfi* foraminiferal zone towards the Cenomanian/Turonian boundary, a relative decrease in the number of species occurred. As a result, the radiolarian faunas in the Czorsztyn, Branisko and Niedzica successions show great similarities. The same

characteristic taxa from the suborder Nassellaria (both cryptorhoracic and cryptocephalic forms) represented by the genera *Holocryptocanium*, *Hemicryptocapsa*, *Squinabullum* and *Cryptamphorella* are the most abundant, while the genera *Dictyomitra*, *Pseudodictyomitra*, *Thanarla*, *Stichomitra*, *Torculum*, and *Xitus* are also common.

2. The next change in radiolarian assemblages took place around the Cenomanian/Turonian boundary. It started during the late Cenomanian (*Rotalipora cushmani* foraminiferal zone, K. Bąk 1998). At that time, the radiolarian assemblages from the Pieniny Succession became similar to those from the Czorsztyn, Niedzica and Branisko successions. Moreover, it was enriched in forms described so far only from the Silesian and the Skole units of the Outer Flysch Carpathians (*Praeconocaryomma lipmanae*, *Godia* sp., *Diacanthocapsa* sp. – see M. Bąk 1994; Górka 1996).

FORAMINIFERAL ASSEMBLAGES

The early and middle Albian Foraminifera in the Pieniny Klippen Belt represent a well-diversified assemblage. Planktonic forms prevail, being represented by hedbergellids (*H. delrioensis*, *H. planispira* and *H. simplex*), *Globigerinelloides bentonensis*, and ticinellids (*Ticinella primula*, *T. roberti*) (K. Bąk 1992). Benthos is dominated by calcareous forms with the most frequent *Gyroidinoides infracretacea*, *Gavelinella cenomanica* and *G. intermedia*, and accompanied by *Dentalina* sp., *Nodosaria* sp. and *Lenticulina* sp. Agglutinated foraminifera (predominantly infaunal forms) are infrequent in these deposits, with *Dorothia gradata*, *Spiroplectinata annectens*, *Tritaxia gaultina* and *Textularia foeda* prevailing.

The upper Albian planktonic Foraminifera are very numerous and more diversified. Besides the most frequent hedbergellids, *Biticinella breggiensis*, *Planomalina buxtorfi*, *Globigerinelloides bentonesis*, *G. ultramicra*, praeglobotruncanids and rotaliporids occur there. Benthos is very rare, dominated by calcareous forms, similar to those present in the older assemblage.

A very similar assemblage is also characteristic of the Cenomanian deposits: planktonic Foraminifera prevail there, with dominating rotaliporids, associated with representatives of the genera *Praeglobotruncana*, *Hedbergella*, *Whiteinella*, *Globigerinelloides*, *Heterohelix* and *Shackoina*. Ratio of calcareous to agglutinated benthic forms is different in pelagic and hemipelagic deposits of this stage. Agglutinated taxa prevail (more than 80% of benthos) in the scaglia rossa-type (Macelowa Marl Member) and flyschoid deposits (Trawne Member, Sneżnica Siltstone Member), being dominated by *Plectorecurvoides alternans*, *Recurvoides* sp., *Bulbobaculites* sp., *Trochammina* sp., *Haplophragmoides* sp., *Spiroplectammina navarroana*, *Arenobulimina preslii*, *Dorothia* sp., *Tritaxia* sp., *Glomospira* sp., and by tubular forms. Calcareous forms are more frequent in variegated and red pelagic marls (Brynczkowa Marl, Skalski Marl and Pustelnia Marl members). However, they are represented by single specimens only. Agglutinated foraminifers include the genera *Dentalina*, *Nodosaria*, *Tristix*, *Lenticulina*, *Marginulinopsis*, *Marginulina*, *Saracenaria*, *Astacolus*, *Planularia*, *Globulina*, *Oolina*, *Pyrulina*, *Ramulina*, *Praebulimina*, *Pleurostomella*, *Valvulineria*, *Pullenia*, *Osangularia*, *Gyroidinoides*, *Gavelinella*, *Lingulogavelinella* and *Eponides*.

A quite different foraminiferal assemblage appears in black shale facies close to the Cenomanian/Turonian boundary. Planktonic Foraminifera are still frequent in the lower part of the shales, being represented predominantly by *Rotalipora cushmani*; they are accompanied by whiteinellids, praeglobotruncanids, hedbergellids and single forms from the genera *Globigerinelloides* and *Heterohelix*. In a higher part of the shales, only single forms of *Praeglobotruncana delrioensis* and *Hedbergella delrioensis* have been found. Benthonic forms are dominated by very frequent *Lenticulina gaultina*. This form is accompanied by single specimens of agglutinated foraminifera from the genera *Bulbobaculites*, *Trochammina*, *Hormosina*, *Glomospira*, *Ammodiscus* and *Rhizammina*.

The middle-late Turonian foraminiferal assemblage considerably differs from the Cenomanian one. Middle Turonian was the acme of *Helvetoglobotruncana helvetica* and *H. praehelvetica*

which characterise this assemblage, while benthonic forms are almost absent. During the late Turonian, benthonic forms become more frequent, and they prevail in the latest Turonian deposits. The benthos is dominated by agglutinated taxa (more than 90%) with very characteristic *Uvigerinammina jankoi*, *Recurvoides godulensis*, *Gerochammina conversa*, *Karrerulina coniformis*, *Haplophragmoides* cf. *bulloides* and *Bulbobaculites problematicus*. Calcareous benthos is represented predominantly by the genera *Eponides*, *Stensioeina* and *Gyroidinoides*.

RADIOLARIAN BIOSTRATIGRAPHY

Radiolarian species were identified in more than 200 samples from 18 sections in the deposits of the Pieniny, Branisko, Niedzica and Czorsztyn successions of the Pieniny Klippen Belt (M. Bąk 1997). Seventeen horizons containing abundant and well-preserved Radiolaria have been chosen for closer analysis (M. Bąk 1999); the BioGraph 2.02 computer program (Savary & Guex 1991) based on the Unitary Associations Method was applied. This program produced a sequence of 11 U. A. (Fig. 3), which were used for constructing a radiolarian zonal standard (M. Bąk 1999). Three radiolarian zones and five subzones were proposed for the early Albian through late Turonian time span (Fig. 3). These are: (1) the *Holocryptocanium barbui* zone with *Stichomitra tosaensis*, *Squinabollum fossile*, *Thanarla veneta*, *Torculum dengoi* and *Obeliscoites maximus* subzones; (2) the *Hemicryptocapsa prepolyhedra* zone; (3) the *Hemicryptocapsa polyhedra* zone. The top of each zone and subzone is defined by the FAD of the index taxon and also by the base of the overlying zone.

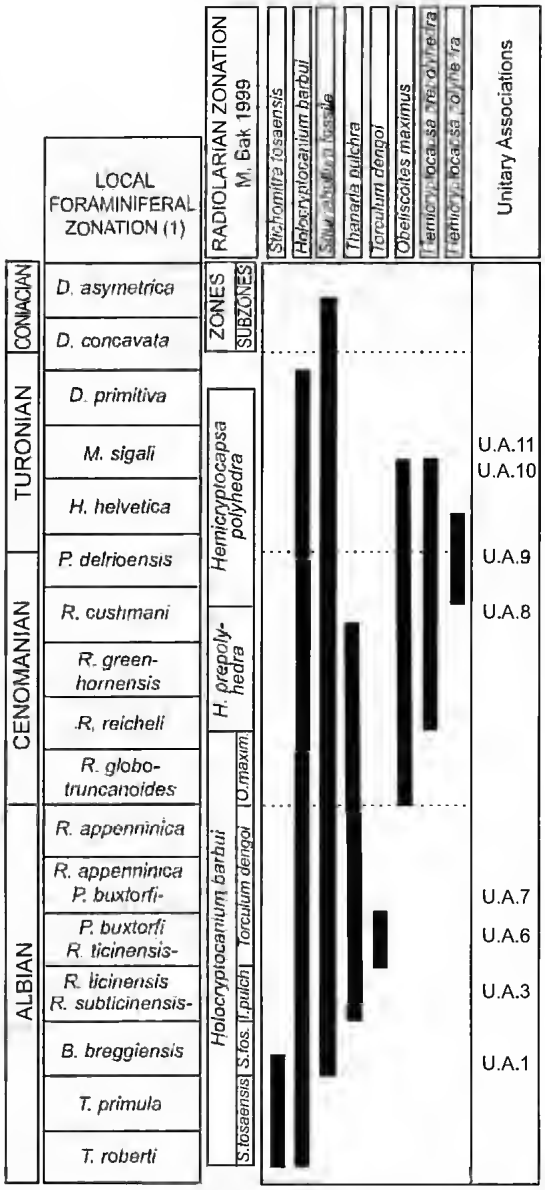

Fig. 3. — Occurrence range chart of index radiolarian species recorded in the Albian to Coniacian deposits in the Pieniny Klippen Belt successions, based on their first and the last appearances, and their co-occurrence based on the Unitary Associations. Abbreviations of zones: **S. tosaensis**, *Stichomitra tosaensis*; **S. fos.**, *Squinabollum fossile*; **T. pulch.**, *Thanarla pulchra*; **O. maxim.**, *Obeliscoites maximus*. **1**, local planktonic foraminiferal zonation after Robaszynski & Caron (1985) modified by K. Bąk (1992, 1998).

FORAMINIFERAL BIOSTRATIGRAPHY

Extensive biostratigraphical studies based on planktonic foraminifera were carried out in Cretaceous deposits of the Polish part of the Pieniny Klippen Belt (Alexandrowicz 1966; Alexandrowicz *et al.* 1968a, 1968b; Jednorowska 1979; Gasiński 1983, 1988; Birkenmajer & Jednorowska 1987; Kostka 1993). The local biozonations have been tied to the zonal standards of the Western Tethys.

The local planktonic biozonation here presented (K. Bąk 1992, 1998), is based on studies of 18 field sections (more than 270 samples) representing deposits from all sedimentary zones of the Pieniny Klippen Basin in Poland. The zones distinguished and their chronostratigraphic calibration, correspond very well with the Mediterranean zonal standard as proposed by Robaszynski & Caron (1995), with only minor revision (for more details, see K. Bąk 1998).
The biozonation based on agglutinated foraminifera follows that proposed for Outer Carpathians by Geroch & Nowak (1984), and applied also to the Pieniny Klippen Belt (K. Bąk *et al.* 1995).

CORRELATION OF RADIOLARIAN ZONATION WITH PLANKTONIC AND AGGLUTINATED FORAMINIFERA ZONES

Various radiolarian zonations for the late Cretaceous deposits were proposed depending on the area concerned. Two proposed standards calibrated with chronostratigraphy in the western part of the Tethys deserve special attention. The first standard was proposed by Dumitrică (1975) for the Romanian Carpathians. He recognised two radiolarian assemblages, the oldet assemblage and the younger one correlated with planktonic foraminifera. The *Holocryptocanium barbui-H. tuberculatum* assemblage corresponds, according to Dumitrică (1975), to the *Rotalipora reicheli-R. cushmani* zone (latest Cenomanian).
O'Dogherty's (1994) standard was more detailed and comprised a calibration with the Northern Apeninnes and Betic Cordillera. This calibration has been based on planktonic Foraminifera partially following the zonal standard as proposed by Caron (1985), with some modifications. O'Dogherty (1994) recognised five radiolarian zones correlated with the *Hedbergella sigali* (Barremian) through the *Marginotruncana sigali* (late Turonian) foraminiferal zones.
In this study, we propose a correlation of radiolarian zones with planktonic and agglutinated foraminiferal zones for the early Albian rhrough late Turonian time span, for the Polish part of the Pieniny Klippen Belt (Fig. 4).

The definition of the *Holocryptocanium barbui* zone used in this zonation follows that of Schaaf's (1985), with some modification of its upper limit. The lower boundary of *H. barbui* zone (= lower boundary of the *Stichomitra tosaensis* subzone) is not well defined, because the earliest Albian and latest Aptian (*Ticinella roberti* planktonic foraminiferal zone and *Haplophragmoides nonioninoides* agglutinated foraminiferal zone) deposits are not well represented in the sections investigated, their radiolarian fauna is rare and poorly preserved. The upper boundary of the *H. barbui* zone falls within a lower part of the *Rotalipora reicheli* planktonic foraminiferal zone and the *Bulbobaculites problematicus* agglutinated foraminiferal zone (middle Cenomanian). The *Squinabollum fossile* radiolarian subzone coincides with the *Biticinella breggiensis* foraminiferal zone (Late Albian). The *Thanarla pulchra* subzone coincides with the *Rotalipora ticinensis-R. subticinensis* foraminiferal zone (late Albian). The lower limit of the *Torculum dengoi* subzone correlates with the upper boundary of the *Rotalipora ticinensis-R. subticinensis* foraminiferal zone. Its upper limit correlates with the upper boundary of the *Rotalipora appenninica* foraminiferal zone (Albian/Cenomanian boundary), and also coincides with the lower limit of the *Obeliscoites maximus* subzone.
The lower boundary of the *Hemicryptocapsa prepolyhedra* zone corresponds to a lower part of the *Rotalipora reicheli* planktonic foraminiferal zone (middle Cenomanian). Its upper boundary (= lower boundary of the *Hemicryptocapsa polyhedra* zone) corresponds to an upper part of the *R. cushmani* planktonic foraminiferal zone (late Cenomanian). The upper boundary of the *H. polyhedra* zone has not been defined within the deposits investigated because the Radiolaria from the latest Turonian and the Coniacian are very poorly preserved (mostly calcified). This zone correlates with the *Rotalipora cushmani* through *Dicarinella primitiva* planktonic foraminiferal zones (= upper part of *Bulbobaculites problematicus* and lower part of *Uvigerinammina* ex gr. *jankoi* agglutinated foraminiferal zones; late Cenomanian through late Turonian).
It is hoped that the proposed radiolarian zonal standard will become a calibration tool to which

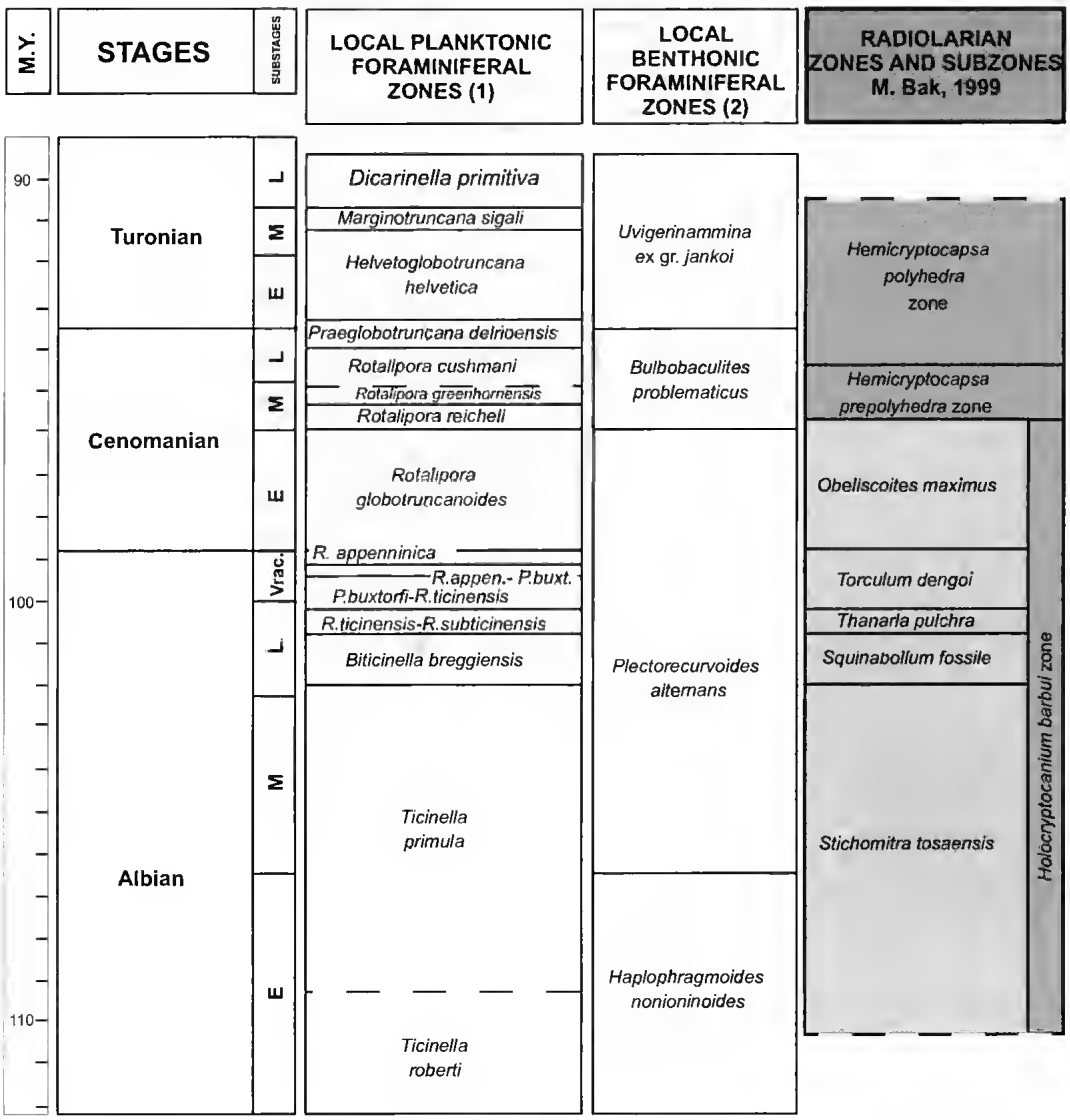

FIG. 4. — Correlation of radiolarian biozones and subzones with planktonic and agglutinated Foraminifera zonations in the Pieniny Klippen Belt, Polish Carpathians [chronological scale after Robaszynski & Caron (1995)]. 1, local planktonic foraminiferal zonation after Robaszynski & Caron (1985) modified by K. Bąk (1992, 1998); 2, local benthonic foraminiferal zonation after Geroch & Nowak (1984) modified by K. Bąk *et al.* (1995), K. Bąk (1995a).

local zonations from other Carpathian regions could be correlated.

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Early Norian Radiolaria from Cyprus

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ABSTRACT
Lower Norian limestones from the Mamonia Complex, southwestern Cyprus, are characterized by diverse radiolarian assemblages. New taxa are described: *Bulbocyrtium latum* n. sp., *Caphtorocyrtium tenerum* n. gen., n. sp., *Capnuchosphaera theloides minor* n. ssp., *Haeckelicyrtium* (?) *carterae* n. sp., *Kinyrosphaera trispinosa* n. gen., n. sp., *K. helicata* n. gen., n. sp., *Nabolella trispinosa* n. sp., *Whalenella robusta* n. sp., and *Xiphotheca* (?) *spinellifera* n. sp.

KEY WORDS
Radiolaria, systematics, Triassic, Norian, Cyprus.

RÉSUMÉ
Radiolaires du Norien inférieur de Chypre.
Des calcaires du Norien inférieur de la formation de Mamonia, sud-ouest de Chypre, sont caractérisés par divers assemblages de radiolaires. De nouveaux taxons sont décrits : *Bulbocyrtium latum* n. sp., *Caphtorocyrtium tenerum* n. gen., n. sp., *Capnuchosphaera theloides minor* n. ssp., *Haeckelicyrtium* (?) *carterae* n. sp., *Kinyrosphaera trispinosa* n. gen., n. sp., *K. helicata* n. gen., n. sp., *Nabolella trispinosa* n. sp., *Whalenella robusta* n. sp. et *Xiphotheca* (?) *spinellifera* n. sp.

MOTS CLÉS
Radiolaires, systématique, Trias, Norien, Chypre.

INTRODUCTION

The presence of Radiolaria in the Triassic sedimentary rocks of Cyprus was indicated by many previous investigators (Lapierre 1975; Robertson & Woodcock 1979; Swarbrick & Robertson 1980). Although these fossils are abundant and well preserved, there is no systematic study of them. Assemblages of the upper Norian were only illustrated before (Bragin & Krylov 1996). This work deals with the diverse lower Norian fauna, which includes many undescribed taxa.
Previous investigators described diverse Carnian and Norian radiolarian assemblages from Sicily, Greece and Turkey (De Wever *et al.* 1979), Austria (Kozur & Mostler 1972; 1979; 1981; Lahm 1984), Croatia (Halamić & Goričan 1995), Japan (Yao 1982; Yoshida 1986; Sugiyama 1997), western North America (Blome 1984; Yeh 1989), Philippines (Yeh 1990), eastern Russia (Bragin 1991). The Carnian to Norian stratigraphic interval was subdivided into radiolarian zones and subzones in the regions of Circum-Pacific belt (Yao 1982; Blome 1984; Bragin 1991; Sugiyama 1997). There are still no such subdivisions for the Mediterranean region and the stratigraphic ranges of numerous taxa remain uncertain. The description of well-dated and extremely diverse radiolarian assemblages from Cyprus will give supplementary data for further research in the Triassic biostratigraphy as well as in the taxonomy and evolution of the Triassic Radiolaria.

GEOLOGICAL SETTING

The Triassic of Cyprus was subdivided into two units: sedimentary and volcanogenous with sedimentary intercalations (Lapierre 1975). Swarbrick & Robertson (1980) defined two important parts of the Mamonia Allochthonous Complex-sedimentary Ayos Photios Group (Middle Triassic-Early Cretaceous) and volcanogenous Dhiarizos Group (Upper Triassic-Jurassic) (Fig. 1). Both these groups are incorporated into complicated allochthonous structures. The detached blocks of the Ayos Photios and Dhiarizos groups are common in the various melanges of the Mamonia Complex. The formations of the Mamonia Allochthonous Complex have wide distribution near Agia Varvara Village, southwestern Cyprus (Fig. 1). This area has an imbricated structure complicated by a system of sublatitudinal and NW-trending strike-slip faults. The lowermost structural unit is composed of the terrigenous melange with blocks derived both from the Troodos Complex and Mamonia Complex. They are overthrusted by series of allochthonous units that are represented by (Fig. 1):

1. Serpentinite melange with blocks of Troodos lavas;
2. Nappe composed of Agia Varvara metamorphics; amphibolites and quartz-mica shists;
3. Serpentinite melange with blocks derived both from the Mamonia Complex and Troodos Complex;
4. Nappe composed of Dhiarizos basic lavas with limestone intercalations (Upper Triassic to Lower Cretaceous).
5. Nappe of Ayos Photios sedimentary group represented by the Upper Triassic clastics (Bragin & Krylov 1996) and the Middle Jurassic to Cretaceous cherts, mudstones, calcarenites and sandstones.

The blocks of sedimentary rocks were studied in the field of terrigenous melange located at 34°45'N, 32°30'E. One of such blocks consists of white and pink platy micritic limestones with intercalations of grey and yellowish-pink cherts with observed thickness 14 m (Fig. 1). This limestone block is interpreted as a sedimentary lense derived from the Triassic part of Dhiarizos Group. This conclusion can be supported by the fact that these limestones did not contain clastic intercalations that are common for the carbonate sediments of the Ayos Photios Group (Swarbrick & Robertson 1980; Bragin & Krylov 1996).
Limestones and cherts contain abundant radiolarians replaced by calcite and recrystallized. Only one sample yielded radiolarians replaced by pyrite. The pyritized radiolarians exhibit well-preserved morphological features. The radiolarian assemblage is characterized by high taxonomic diversity. Radiolaria are represented by the following taxa: *Annulotriassocampe* sp. cf. *A. sulovensis*

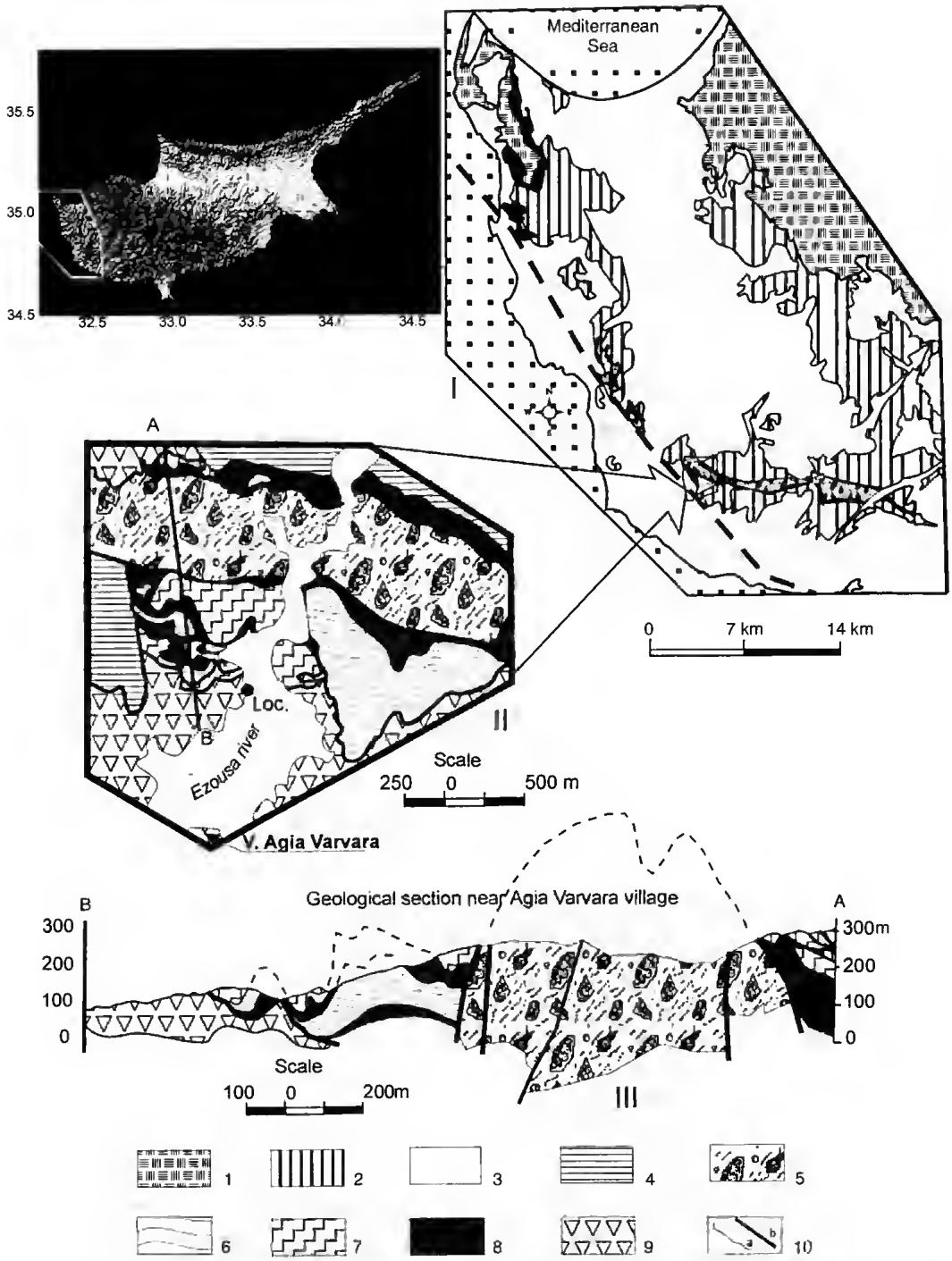

FIG. 1. — Geological position of the Upper Triassic radiolarian-bearing limestones in the southwestern Cyprus. **I**, map showing generalized geological position of the Mamonia Allochthonous Complex in the southwestern Cyprus; **II**, geological map of the Agia Varvara area (**Loc.**, position of studied limestone block); **III**, geological section A-B. Legend: **1**, Troodos Complex; **2**, Mamonia Allochthonous Complex; **3**, Cenozoic sediments; **4**, Ayos Photios Group (Upper Triassic-Cretaceous); **5**, serpentinite melange with Troodos blocks; **6**, Agia Varvara metamorphics; **7**, Dhiarizos Group (volcanics with limestone intercalations, Upper Triassic-Lower Cretaceous); **8**, serpentinite melange with Mamonia blocks; **9**, terrigenous melange; **10**, boundaries; **a**, stratigraphic; **b**, tectonic.

(Kozur & Mock, 1981), *Archaeocenosphaera* sp., *Bulbocyrtium latum* Bragin n. sp., *Caphtorocyrtium tenerum* Bragin n. gen., n. sp., *Capnodoce ruesti* Kozur & Mock, 1981, *Capnuchosphaera deweveri* Kozur & Mostler, 1979, *C.* sp. cf. *C. deweveri* Kozur & Mostler, 1979, *C. theloides minor* Bragin n. ssp., *C.* sp. cf. *C. theloides* De Wever, 1979, *C.* sp. aff. *C. carpathica* Kozur & Mock, 1981, Capnuchosphaeridae n. gen., sp. indet., *Carinabeliosoma carinata* (Kozur & Mostler, 1979), *Entactinosphaera* sp. aff. *E. simoni* Kozur & Mostler, 1979, *E.* (?) sp. 1, *E.* (?) sp. 2, *Ferresium* sp. aff. *F. conclusum* Carter, 1993, *Foremanellina* (?) sp., *Haeckelicyrtium carterae* Bragin n. sp., *Heliosoma* (?) *riedeli* Kozur & Mostler, 1981, *Heliosoma* (?) sp., *Icrioma tetrancistrum* De Wever, 1979, *I.* sp. aff. *I. tetrancistrum* De Wever, 1979, *Kahlerosphaera aspinosa* Kozur & Mock, 1981, *K. norica* Kozur & Mostler, 1979, *Karnospongella bispinosa* Kozur & Mostler, 1981, *Kinyrosphaera trispinosa* Bragin n. gen., n. sp., *K. helicata* Bragin n. gen., n. sp., *Kinyrosphaera* (?) sp., *Laxtorum* (?) sp., *Liassosaturnalis parvus* Kozur & Mostler, 1990, *Loffa* (?) sp., *Multimonilis pulcher* Yeh, 1989, *Nabolella trispinosa* Bragin n. sp., *Napora* (?) sp. 1, *N.* sp. 2, *Neopylentonema* sp. aff. *N. procera* Sugiyama, 1997, *Palaeosaturnalis triassicus* (Kozur & Mostler, 1972), *P. latiannulatus* Kozur & Mostler, 1983, *P. mocki* Kozur & Mostler, 1983, *Paronaella norica* Kozur & Mock, 1981, *Paronaella* sp., *Pentactinocarpus* sp. aff. *P. tetracanthus* Dumitrica, 1978, *Pentactinocarpus* sp., *Praemesosaturnalis* sp. cf. *P. multidentatus* (Kozur & Mostler, 1972), *Pentaspongodiscus* sp. 1, *P.* sp. 2, *Poulpus piabyx* De Wever, 1979, *Pseudosaturniforma carnica* Kozur & Mostler, 1979, *Praenanina veghae* Kozur, 1994, *Praeorbiculiformella goestlingensis* Kozur & Mostler, 1978, *Pseudostylosphaera* (?) sp., *Sarla* (?) sp., *Sepsagon* sp., *Setbucapsa* sp., *Spongostylus carnicus* Kozur & Mostler, 1979, *S. tortilis* Kozur & Mostler, 1979, *Sulovella constricta* Kozur & Mock, 1981, *Syringocapsa batodes* De Wever, 1979, *Syringocapsa* sp., *Trialatus robustus* (Nakaseko & Nishimura, 1979), *Triassobipedis* (?) sp., Triassocampidae n. gen., sp. indet., *Triassocrucella triassica* (Kozur & Mostler, 1978), *Veghicyclia* sp. cf. *V. robusta* Kozur & Mostler, 1972, *Vinassaspongus transitus* Kozur & Mock, 1981, *Whalenella* sp. aff. *W. perfecta* (Blome, 1984), *W. robusta* Bragin n. sp., *Xiphotheca rugosa* Bragin, 1991, *X. longa* Kozur & Mock, 1981, *X.* (?) *spinellifera* Bragin n. sp., *Xiphotheca* sp., *Xiphotheca* (?) sp., *Zbamojdasphaera proceruspinosa* Lahm, 1984. All these radiolarians come from a single sample.

The early Norian age of this assemblage is confirmed by the presence of conodonts *Epigondolella spatulata* (Hayashi) and such radiolarian taxa as *Capnodoce ruesti*, *Sulovella constricta* and *Vinassaspongus transitus*. Radiolarian assemblage is typical for the *Capnodoce ruesti* zone (Kozur & Mostler 1994) with some exceptions. Some species were known only from Carnian or older deposits: *Karnospongella bispinosa*, *Praenanina veghae*, *Spongostylus carnicus*. The locality from Cyprus may represent a latest occurrence of these taxa.

SYSTEMATICS

Subclass RADIOLARIA Müller, 1858
Order POLYCYSTINA Ehrenberg, 1838
Suborder SPUMELLARIA Ehrenberg, 1875
Superfamily HEXASTYLACEA Haeckel, 1862
Family ENTACTINIIDAE Riedel, 1967a

Genus *Entactinosphaera* Foreman, 1963

TYPE SPECIES. — *Entactinosphaera esostrongyla* Foreman, 1963.

Entactinosphaera sp. aff. *E. simoni* Kozur & Mostler, 1979 (Fig. 3C)

aff. *Entactinosphaera ? simoni* Kozur & Mostler, 1979: 72, pl. 4, fig. 5; pl. 7, fig. 2; pl. 8, fig. 1. – Lahm 1984: 17, pl. 1, fig. 10.

OCCURRENCE. — Lower Norian of Cyprus.

DESCRIPTION

Small spherical shell with six symetrically arranged spines, four of them in the same plane. Spines long, robust, Y-shaped. Cortical shell one-

layered, with prominent pores in irregular hexagonal to pentagonal pore frames.

REMARKS
This form differs from *E. simoni* Kozur & Mostler by more spherical cortical shell with robust spines.

Entactinosphaera **(?)** sp. 1
(Figs 2H, 3F)

DESCRIPTION
Shell spherical with four three-bladed spines lying in one plane. Distal parts of spines sometimes display small sinistral torsion. Shell with subspherical pores that are variable in size and enclosed in rectangular pore frames with prominent nodes at vertices. Shell surface sometimes with small thin secondary spines.

REMARKS
Although the external morphology is well preserved, the inner structure is uncertain. These forms are assigned tentatively to genus *Entactinosphaera*.

Entactinosphaera **(?)** sp. 2
(Fig. 3A)

REMARKS
Uncomplete specimen with visible inner shell illustrated. Nevertheless, the internal spicule cannot be observed due to the preservation (replacement by pyrite).

Family SEPSAGONIDAE
Kozur & Mostler, 1981

Genus *Sepsagon*
Dumitrica, Kozur & Mostler, 1980

TYPE SPECIES. — *Triactoma longispinosum* Kozur & Mostler, 1979.

Sepsagon sp.
(Fig. 3E)

DESCRIPTION
Shell subspherical with rough nodose surface, with small pores in rectangular pore frames. Three main spines long, curved, with Y-shaped cross-section and moderately developed dextral torsion.

REMARKS
Only one specimen was observed.

Genus *Pseudostylosphaera*
Kozur & Mostler, 1981

TYPE SPECIES. — *Pseudostylosphaera gracilis* Kozur & Mock, 1981.

Pseudostylosphaera **(?)** sp.
(Fig. 7I)

REMARKS
This form is characterized by short thin apophyses at the median parts of the main spines. It did not represent a typical double layered shell of *Pseudostylosphaera* and may belong to another genus.

Family HEXAPYLOMELLIDAE
Kozur & Mostler, 1979

Genus *Praenanina* Kozur, 1994

TYPE SPECIES. — *Praenanina veghae* Kozur, 1994.

Praenanina veghae Kozur, 1994
(Fig. 2B, C, E)

Praenanina veghae Kozur, 1994 *in* Kozur & Mostler, 1994: 247, pl. 2A, fig. 2; pl. 4A, figs 1, 3.

OCCURRENCE. — Middle (?) to upper Carnian of Hungary, lower Norian of Cyprus.

Family PENTACTINOCARPIDAE
Dumitrica, 1978

Genus *Pentactinocarpus* Dumitrica, 1978

TYPE SPECIES. — *Pentactinocarpus fusiformis* Dumitrica, 1978.

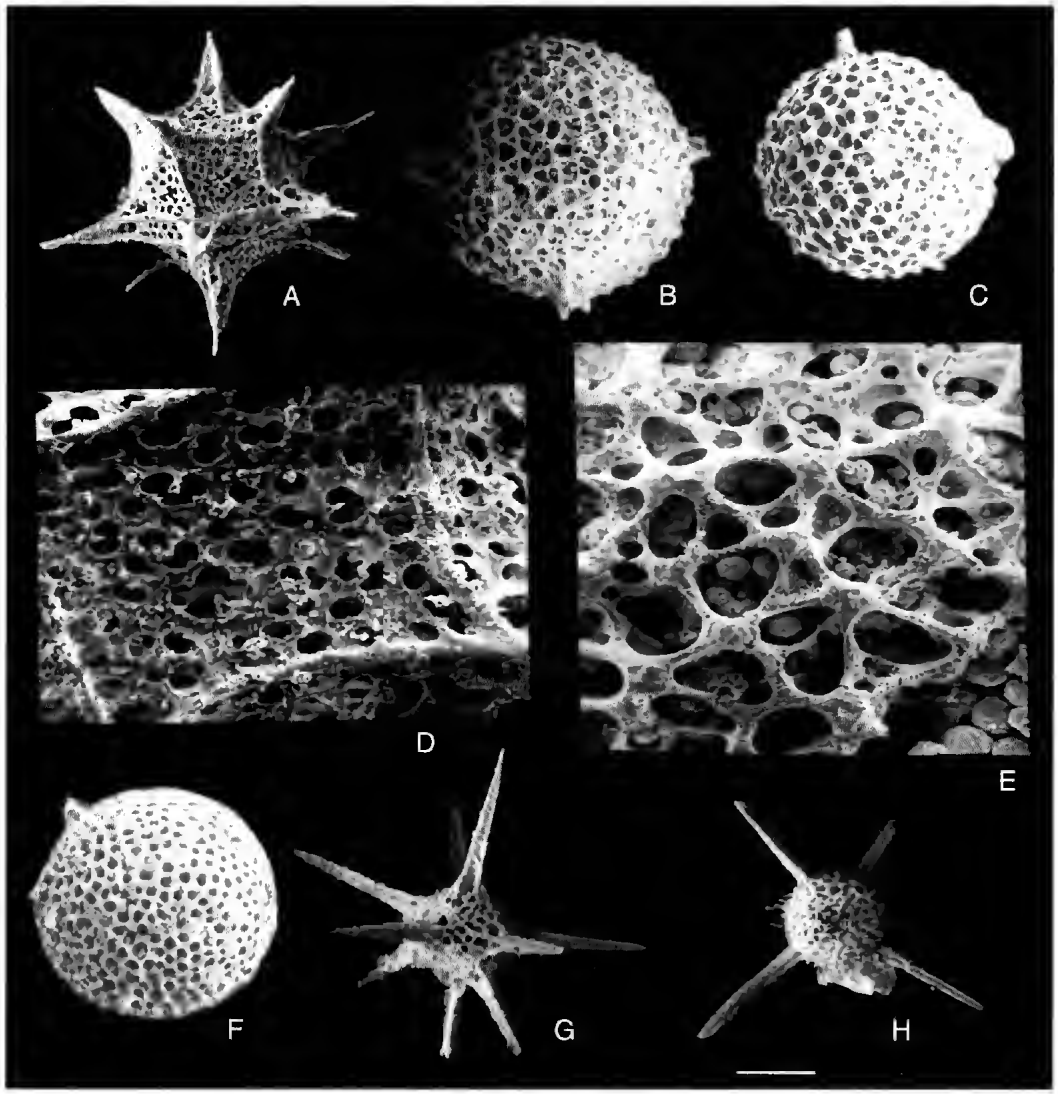

FIG. 2. — **A-D**, *Carinaheliosoma carinata* Kozur & Mostler; **D**, detail; **B**, **C**, **E**, *Praenanina veghae* Kozur; **E**, detail; **F**, *Archaeocenosphaera* sp.; **G**, *Heliosoma* (?) sp.; **H**, *Entactinosphaera* (?) sp. 1. Scale bar: A, B, C, F, 100 µm; D, E, 20 µm; G, H, 200 µm.

Pentactinocarpus sp.
aff. ***P. tetracanthus*** Dumitrica, 1978
(Fig. 7D)

REMARKS
This form differs from *Pentactinocarpus tetracanthus* (Dumitrica, 1978: 44, pl. 2, fig. 1) by larger and wider test. It differs from *P. sevaticus* (Kozur & Mostler, 1981: 21, pl. 52, fig. 3, pl. 53, figs 2, 5, pl. 55, fig. 1) by more delicate meshwork of cortical shell with smaller pores in hexagonal to pentagonal pore frames with small nodes at vertices. *P. magnus* (Kozur & Mostler, 1979: 55, pl. 10, fig. 1) has larger pores enclosed in the variable polygonal pore frames without nodes at vertices.

Pentactinocarpus sp.
(Fig. 7E)

REMARKS
This form possesses a delicate small test with

very thin and long apical, antapical and basal spines. The position of basal spines is similar to those of *Pentactinocarpus tetracanthus* Dumitrica but specimen from Cyprus differs by small size of test and by thin network-like meshwork of a cortical shell.

Superfamily ACTINOMMACEA Haeckel, 1862
Family XIPHOSTYLIDAE Haeckel, 1881

Genus *Archaeocenosphaera*
Pessagno & Yang, 1989

TYPE SPECIES. — *Archaeocenosphaera ruesti* Pessagno & Yang, 1989.

Archaeocenosphaera sp.
(Fig. 2F)

REMARKS
This form is similar to *Archaeocenosphaera* sp. aff. *A. laseekensis* Pessagno & Yang (Carter 1993: 67, pl. 1, figs 14, 19, 20). It differs by smaller test with pores that are more uniform in size.

Family ACTINOMMIDAE Haeckel, 1862

Genus *Carinaheliosoma*
Kozur & Mostler, 1981

TYPE SPECIES. — *Carinaheliosoma densiporata* Kozur & Mock, 1981.

Carinaheliosoma carinata
(Kozur & Mostler, 1979)
(Fig. 2A, D)

Heliosoma carinata Kozur & Mostler, 1979: 52, pl. 9, fig. 1-3.
Carinaheliosoma carinata (Kozur & Mostler, 1979) – Lahm 1984: 65, pl. 11, fig. 8.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian of the European Tethys.

Genus *Heliosoma* Haeckel, 1882
emend. Kozur & Mostler, 1979

TYPE SPECIES. — *Heliosoma radians* Haeckel, 1887.

Heliosoma* (?) *riedeli
Kozur & Mostler, 1981
(Fig. 3B, D)

Heliosoma (?) *riedeli* Kozur & Mostler, 1981: 65, pl. 1, fig. 4. – Lahm 1984: 63, pl. 11, figs 2, 3.

OCCURRENCE. — Middle Triassic, Ladinian, Upper Triassic, Carnian (?) to lower Norian of the European Tethys.

***Heliosoma* (?) sp.**
(Fig. 2G)

DESCRIPTION
Small roughly subspherical to rectangular test with ten long thin three-bladed spines. Cortical shell with small roughly subcircular pores. Proximal parts of spines with deep grooves that become narrow at the middle parts and disappear at the distal parts.

REMARKS
This form differs from *Heliosoma* (?) *riedeli* Kozur & Mostler by small size of cortical shell and its roughly spherical to rectangular shape.

Genus *Kahlerosphaera*
Kozur & Mostler, 1979

TYPE SPECIES. — *Kahlerosphaera parvispinosa* Kozur & Mostler, 1979.

Kahlerosphaera aspinosa
Kozur & Mock, 1981
(Fig. 7A)

Kahlerosphaera ? *aspinosa* Kozur & Mock, 1981 *in* Kozur & Mostler, 1981: 36, pl. 47, fig. 3.

OCCURRENCE. — Upper Triassic, lower Norian of the European Tethys.

Kahlerosphaera norica
Kozur & Mock, 1979
(Fig. 6G, H)

Kahlerosphaera norica Kozur & Mock, 1981 *in* Kozur & Mostler, 1981: 36, pl. 15, fig. 4.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian of the European Tethys.

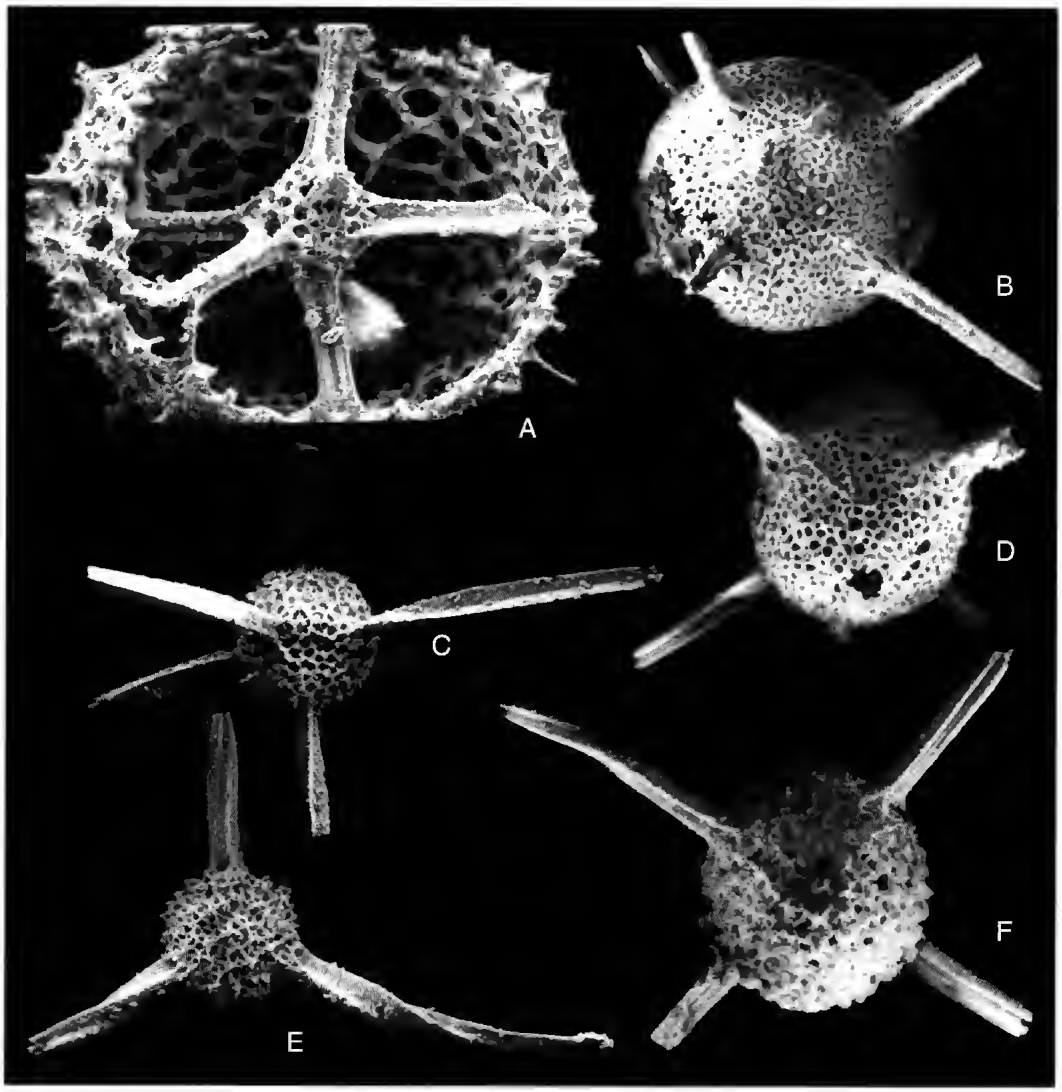

FIG. 3. — **A**, *Entactinosphaera* (?) sp. 1; **B**, **D**, *Heliosoma* (?) *riedeli* Kozur & Mostler; **C**, *Entactinosphaera* sp. aff. *E. simoni* Kozur & Mostler; **E**, *Sepsagon* sp.; **F**, *Entactinosphaera* (?) sp. 1. Scale bar: A, 50 µm; B-F, 100 µm.

Genus *Vinassaspongus*
Kozur & Mostler, 1979

TYPE SPECIES. — *Vinassaspongus subsphaericus* Kozur & Mostler, 1979.

Vinassaspongus transitus
Kozur & Mock, 1981
(Fig. 6D, F)

Vinassaspongus transitus Kozur & Mock, 1981 *in* Kozur & Mostler, 1981: 69, pl. 64, figs 1, 2.

OCCURRENCE. — Upper Triassic, lower Norian of the European Tethys.

Genus *Zhamojdasphaera*
Kozur & Mostler, 1979

TYPE SPECIES. — *Zhamojdasphaera latispinosa* Kozur & Mostler, 1979.

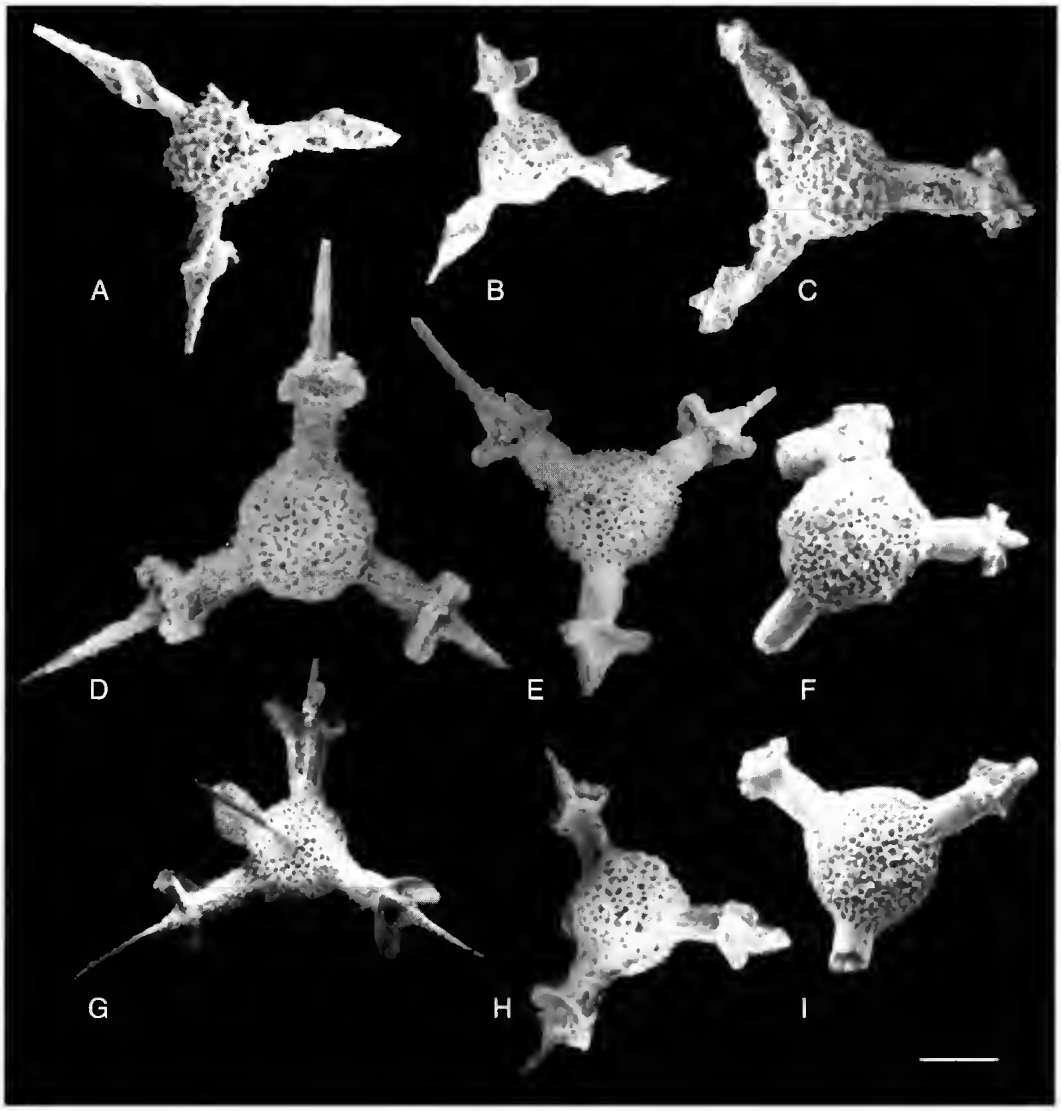

FIG. 4. — **A**, *Capnuchosphaera deweveri* Kozur & Mostler; **B**, *Capnuchosphaera* sp. cf. *C. deweveri* Kozur & Mostler; **C**, *Sarla* (?) sp.; **D**, **E**, *Capnuchosphaera theloides minor* Bragin n. ssp.; **E**, holotype; **F**, **H**, **I**, *Capnuchosphaera* sp. cf. *C. theloides* De Wever; **G**, *Capnuchosphaera* sp. aff. *C. carpathica* Kozur & Mock. Scale bar: A-C, F-I, 100 µm; D, E, 80 µm.

Zhamojdasphaera proceruspinosa
Lahm, 1984
(Fig. 8E)

Zhamojdasphaera proceruspinosa Lahm, 1984: 75, pl. 13, fig. 6.

OCCURRENCE. — Upper Triassic, Carnian-lower Norian of the Tethys.

Family CAPNUCHOSPHAERIDAE
De Wever, 1979
Genus *Capnuchosphaera* De Wever, 1979

TYPE SPECIES. — *Capnuchosphaera triassica* De Wever, 1979.

Capnuchosphaera deweveri
Kozur & Mostler, 1979
(Fig. 4A)

Capnuchosphaera triassica var. a De Wever, 1979: 84, pl. 4, figs 3-5.
Capnuchosphaera deweveri Kozur & Mostler, 1979: 77, pl. 10, figs 2, 4-8; pl. 12, fig. 1. – De Wever 1982: 152, pl. 3, figs 10, 11; pl. 4, figs 1, 2. – Blome 1983: 16, pl. 1, figs 3, 8, 9, 16, 18; pl. 11, figs 1, 2, 16. – Lahm 1984: 81, pl. 14, fig. 7. – Yeh 1990: 8, pl. 2, fig. 5; pl. 10, fig. 8.

OCCURRENCE. — Upper Carnian to lower Norian of European Tethys and Pacific coastal areas.

Capnuchosphaera sp.
cf. *C. deweveri* Kozur & Mostler, 1979
(Fig. 4B)

aff. *Capnuchosphaera deweveri* Kozur & Mostler, 1979: 75, pl. 10, figs 4-7; pl. 12, fig. 1.

REMARKS
This form has shorter and thicker tumidaspinae than *C. deweveri* Kozur & Mostler. The new taxon cannot be described because of poor preservation.

Capnuchosphaera theloides minor
Bragin n. ssp.
(Fig. 4D, E)

Capnuchosphaera theloides var. a De Wever, 1979: p. 84, pl. 4, fig. 1. – Nakaseko & Nishimura 1979: p. 75, pl. 7, fig. 7. – De Wever 1982: 158, pl. 6, fig. 8.
Capnuchosphaera theloides – Yao 1982: pl. 1, fig. 23. – Yoshida 1986: pl. 12, fig. 4. – Bragin 1991a: p. 77, pl. 5, figs 14, 15.

HOLOTYPE. — Fig. 4E, GIN-4858-42. Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — Minor (Latin)-younger.

DIMENSIONS (based on five specimens). — Diameter of cortical shell 130-135 µm, total length of spines 220-260 µm, length of distal rod-like parts of spines 145-160 µm, maximal width of spines 80-90 µm.

OCCURRENCE. — Upper Triassic, upper Carnian to lower Norian of European Tethys, Japan and eastern Russia.

DESCRIPTION
Cortical shell spherical with three tumidaspinae situated in the same plane. Proximal parts of tumidaspinae smooth, moderately thick, central parts three-bladed, tetrahedrical, without torsion, distal parts very long and thin without clear differentiation from central parts. Cortical shell perforated by small circular pores in the irregular thorny pore frames.

REMARKS
These forms differ from *Capnuchosphaera theloides theloides* (De Wever, 1979: 83, pl. 3, figs 10-13) by the character of tumidaspinae with thinner proximal parts and longer distal parts that are not well differentiated from the central tetrahedrical parts.

Capnuchosphaera sp.
cf. *C. theloides* De Wever, 1979
(Fig. 4F, H, I)

cf. *Capnuchosphaera theloides* De Wever, 1979: 83, 84, pl. 3, figs 10-13; pl. 4, fig. 1.

REMARKS
This form has poorly preserved central and distal parts of tumidaspinae. Due to this preservation it is difficult to give a precise determination.

Capnuchosphaera sp.
aff. *C. carpathica* Kozur & Mock, 1981
(Fig. 4G)

aff. *Capnuchosphaera carpathica* Kozur & Mock, 1981: 74, pl. 48, fig. 5.

OCCURRENCE. — Upper Triassic, lower Norian of Cyprus.

DESCRIPTION
Cortical shell subspherical with three tumidaspinae in the same plane and thin rod-like additional spine perpendicular to the tumidaspinae. Tumidaspinae with moderately thick proximal parts, central parts subtetrahedrical, concave, without torsion, distal parts long and thin. Cortical shell with small subcircular pores in irregular pore frames.

REMARKS
This form differs from *C. carpathica* Kozur & Mock by more concave character of tumidaspinae and by the presence of additional spine.

Genus *Sarla* Pessagno, 1979

TYPE SPECIES. — *Sarla prietoensis* Pessagno, 1979.

Sarla (?) sp.
(Fig. 4C)

DESCRIPTION
Cortical shell subspherical, slightly flattened to subdiscoidal, with three spines in the same plane. Spines three-bladed, without torsion, with slightly inflated middle parts. Distal parts of spines with tetragonal-like structures, poorly preserved. Pores of shell small, subcircular, enclosed in irregular pore frames.

REMARKS
Only one specimen was found. It is similar to *Eptingium* sp. A (De Wever 1982: 277, pl. 35, figs 3, 4; Grapes *et al.* 1990, fig. 9h) but possesses more inflated shell. Due to poor preservation, it is difficult to conclude that it is the same species as illustrated by De Wever. The generic assignment is under question. The terminations of spines resemble similar structures of *Kahlerosphaera*.

Genus *Sulovella* Kozur & Mock, 1981

TYPE SPECIES. — *Sulovella constricta* Kozur & Mock, 1981.

Sulovella constricta
Kozur & Mock, 1981
(Fig. 5A, B)

Sulovella constricta Kozur & Mock, 1981 *in* Kozur & Mostler, 1981: 77, pl. 64, fig. 2.
Capnuchosphaera cf. *constricta* – Halamič & Goričan 1995: pl. 2, fig. 11.
? *Capnuchosphaera crassa* Yeh, 1990: 8, pl. 1, figs 8, 11-13, 18, 19. – Halamič & Goričan 1995: pl. 2, fig. 12.

OCCURRENCE. — Upper Triassic, lower Norian of Carpathians, Croatia, Philippines (?) and Cyprus.

Genus *Icrioma* De Wever, 1979

TYPE SPECIES. — *Icrioma tetrancistrum* De Wever, 1979.

Icrioma tetrancistrum De Wever, 1979
(Fig. 5G)

Icrioma tetrancistrum De Wever, 1979: 86, pl. 4, figs 13-15; 1982: 262, pl. 22, figs 1-6.

OCCURRENCE. — Upper Triassic, upper Carnian to lower Norian, European Tethys.

Icrioma sp. aff. ***I. tetrancistrum***
De Wever, 1979
(Fig. 5I)

REMARKS
This form differs from *Icrioma tetrancistrum* De Wever by tetrahedrical rather then subspherical form of shell with arms less well differentiated from the central part of shell.

Genus *Kinyrosphaera* Bragin n. gen.

TYPE SPECIES. — *Kinyrosphaera trispinosa* n. sp.

SPECIES INCLUDED. — *Kinyrosphaera trispinosa* Bragin n. sp., *K. helicata* Bragin n. sp.

ETYMOLOGY. — Kinyras (Greek), legendary king of Cyprus, founder of pre-Greek Cypriot dynasty.

OCCURRENCE. — Upper Triassic, lower Norian of Cyprus.

DESCRIPTION
Capnuchosphaeridae with three spines partly covered by porous extensions of cortical shell. Cortical shell spherical or subspherical, with wall typical for the family. Central parts of spines with three large pores, distal parts thin, sometimes rod-like.

REMARKS
Kinyrosphaera Bragin n. gen. differs from *Icrioma* De Wever by presence of three spines, from *Capnuchosphaera* De Wever by porous extensions of cortical shell to the proximal parts of spines.

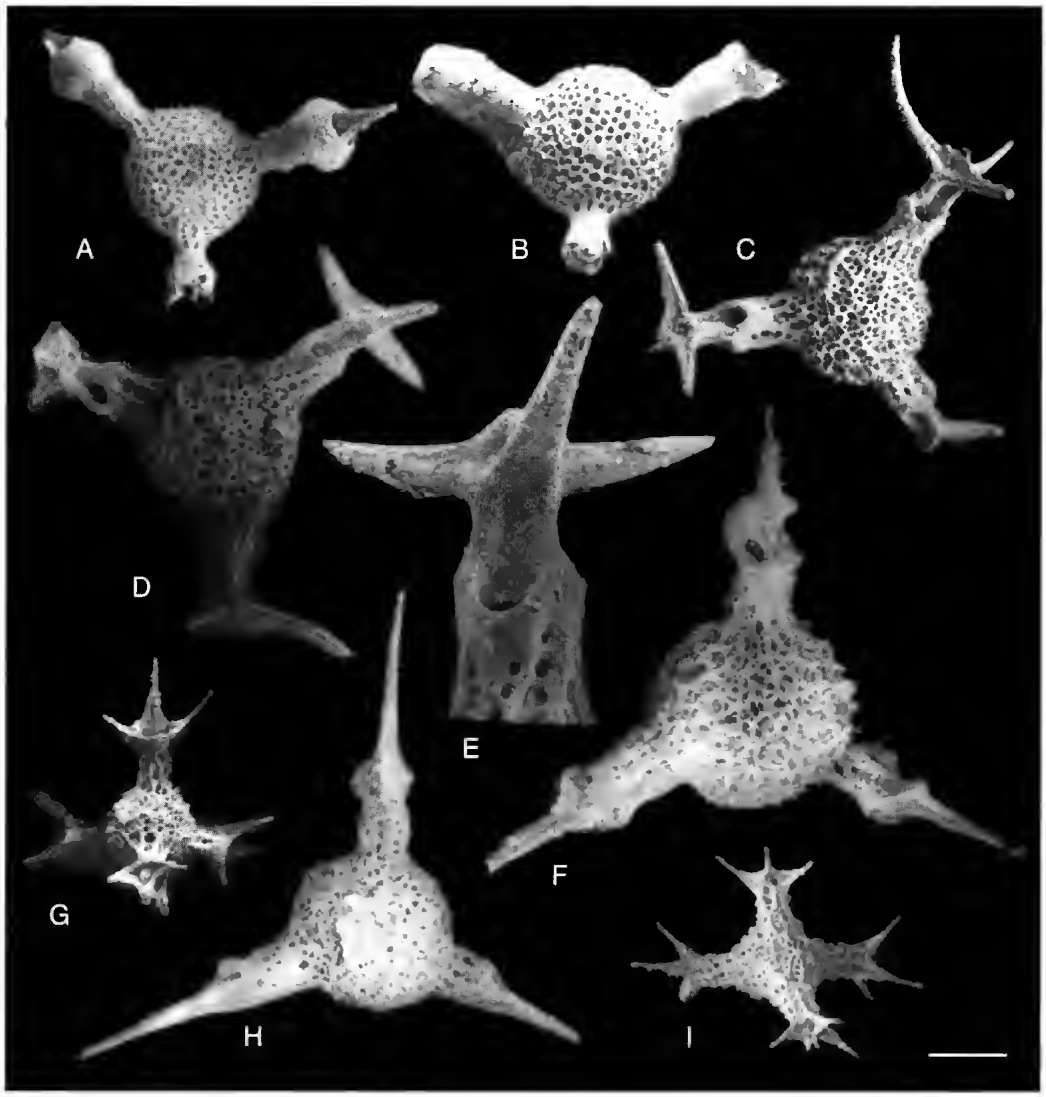

FIG. 5. — **A**, **B**, *Sulovella constricta* Kozur & Mock; **C-E**, *Kinyrosphaera trispinosa* Bragin n. gen., n. sp.; **C**, holotype; **D**, detail of spine; **F**, **H**, *Kinyrosphaera helicata* Bragin n. gen., n. sp.; **F**, holotype; **G**, *Icrioma tetrancistrum* De Wever; **I**, *Icrioma* sp. aff. *I. tetrancistrum* De Wever. Scale bar: A-C, G, I, 100 µm; D, F, H, 80 µm; E, 35 µm.

Kinyrosphaera trispinosa Bragin n. sp. (Fig. 5C-E)

HOLOTYPE. — Fig. 5C, GIN-4858-49, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — *Trispinosa* (Latin), with three spines.

OCCURRENCE. — Upper Triassic, lower Norian of Cyprus.

DIMENSIONS (based on eight specimens). — Diameter of cortical shell 155-180 µm, length of spines without terminal parts 140-155 µm.

DESCRIPTION

Cortical shell spherical with nodose surface, with small subcircular to subrectangular pores in weakly developed rectangular pore frames. Spines moderately long, lie in the same plane. Proximal parts of spines short, cylindrical, with small sub-

circular pores arranged in longitudinal rows sometimes displaying small dextral twisting. Central parts of spines Y-shaped in cross-section, with three large pores. Distal parts of spines are divided into three rod-like terminations slightly curved distally with small smooth node at their joints.

REMARKS
Kinyrosphaera trispinosa Bragin n. gen., n. sp. differs from *K. helicata* Bragin n. gen., n. sp. by non-twisted central parts of spines and by trifurcation of distal parts of spines.

Kinyrosphaera helicata Bragin n. sp.
(Figs 5F, H, 6A)

? *Capnuchosphaera* (?) sp. – Halamič & Goričan 1995: pl. 2, fig. 10.

HOLOTYPE. — Fig. 5F, GIN-4858-51, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — Helix (Greek), spiral shell.

OCCURRENCE. — Upper Triassic, lower Norian of Cyprus, upper Carnian of Croatia.

DIMENSIONS. — Diameter of cortical shell 160-200 µm, total length of spines 220-270 µm, maximal width of spines 60-80 µm.

DESCRIPTION
Cortical shell spherical with nodose surface, with small subcircular to subrectangular pores in weakly developed rectangular pore frames. Spines long, lie in the same plane. Proximal parts of spines cylindrical, with small subcircular pores arranged in longitudinal rows and with longitudinal ridges between rows of pores. Central parts of spines strongly twisted sinistrally, Y-shaped in cross-section, with three large pores. Distal parts of spines long, thin, rod-like.

REMARKS
Kinyrosphaera helicata Bragin n. gen., n. sp. differs from *K. trispinosa* Bragin n. gen., n. sp. by the twisting of central parts of spines and by the long rod-like distal parts of spines.

Kinyrosphaera (?) sp.
(Fig. 6B)

REMARKS
This form has three porous extensions of the cortical shell at three main spines, but does not display typical Y-shaped in cross-section median parts of spines. Only one specimen was observed.

Capnuchosphaeridae gen. *et* sp. indet.
(Fig. 6E)

REMARKS
This form has four tetrahedrically arranged solid twisted spines. It differs from the representatives of genus *Sarla* Pessagno by the number of spines.

Family PANTANELLIIDAE Pessagno, 1977
Subfamily CAPNODOCINAE Pessagno, 1979

Genus *Capnodoce* De Wever, 1979

TYPE SPECIES. — *Capnodoce anapetes* De Wever, 1979.

Capnodoce ruesti Kozur & Mock, 1981
(Fig. 7B, C)

Capnodoce ruesti Kozur & Mock, 1981, *in* Kozur & Mostler, 1981: 74, fig. 65, fig. 2.

OCCURRENCE. — Upper Triassic, lower Norian of Carpathians and Cyprus.

Genus *Loffa* Pessagno, 1979

TYPE SPECIES. — *Loffa mulleri* Pessagno, 1979.

Loffa (?) sp.
(Fig. 6C)

DESCRIPTION
Shell subtetrahedrical, spongy, with four tubular spines (typical for Subfamily Capnodocinae). Spines tetrahedrically placed, smooth, each with three internal channels which end by three pores at terminations.

REMARKS
This form belongs to genus *Loffa* Pessagno due to the presence of four smooth tubular spines

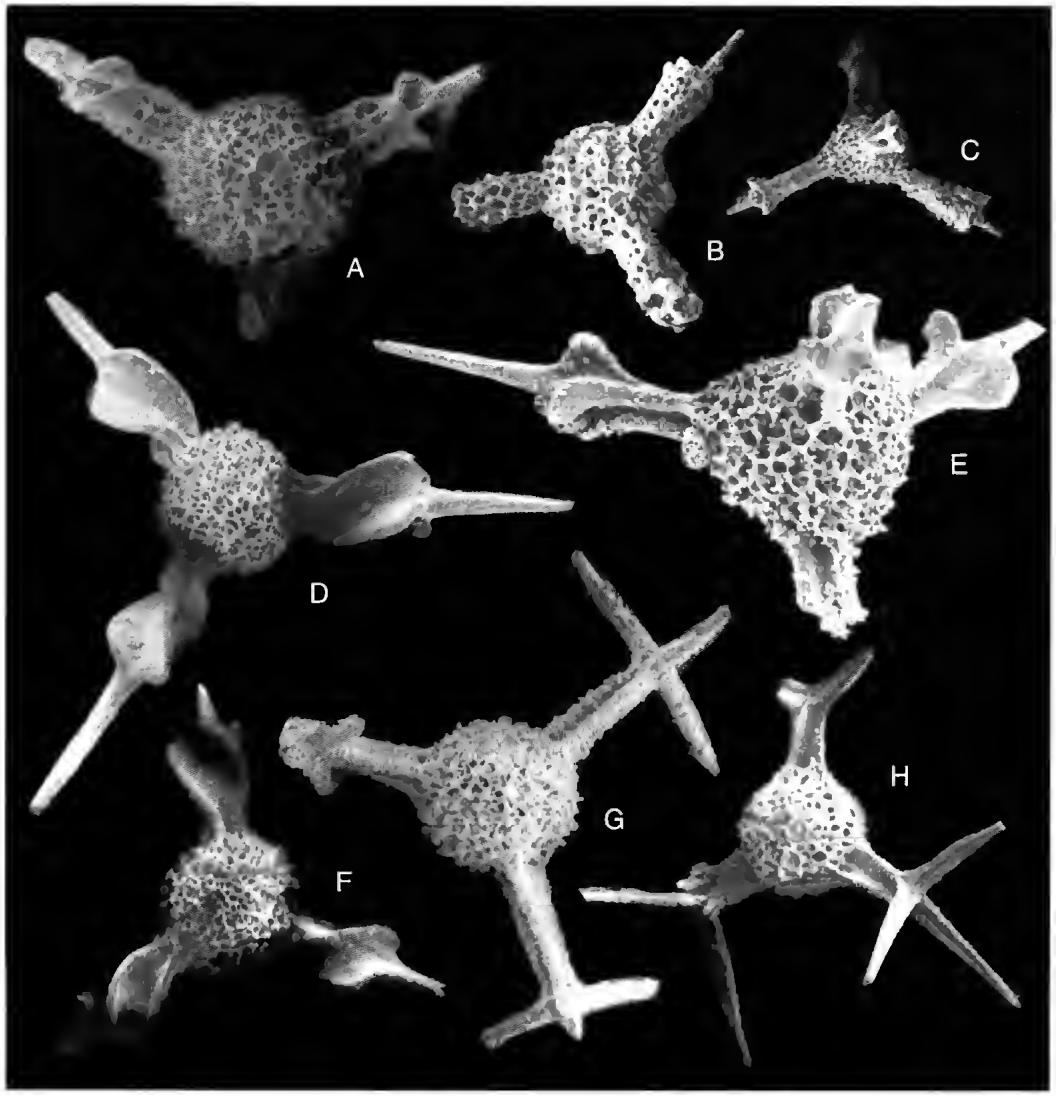

FIG. 6. — **A**, *Kinyrosphaera helicata* Bragin n. gen., n. sp.; **B**, *Kinyrosphaera* (?) sp.; **C**, *Loffa* (?) sp.; **D**, **F**, *Vinassaspongus transitus* Kozur & Mock; **E**, Capnuchosphaeridae gen. *et* sp. indet.; **G**, **H**, *Kahlerosphaera norica* Kozur & Mock. Scale bar: B, C, F, H, 100 µm; A, D, G, 80 µm, E, 50 µm.

without porous extensions of a cortical shell. It is characterized by irregularly spongy meshwork of shell and by thicker spines than other representatives of genus *Loffa*.

Superfamily SPONGODISCACEA Haeckel, 1862
Family SPONGURIDAE Haeckel, 1862

Genus *Spongostylus* Haeckel, 1882

TYPE SPECIES. — *Spongostylus hastatus* Haeckel, 1882.

Spongostylus carnicus
Kozur & Mostler, 1979
(Fig. 7F)

Spongostylus carnicus Kozur & Mostler, 1979: 58, pl. 9, figs 5, 6, 8, 9; 1981, pl. 38, fig. 3. – Lahm 1984: 69, pl. 12, fig. 4. – Carter *et al.* 1989: pl. 1, fig. 5. – Yeh 1989: 67, pl. 13, fig. 8. – Grapes *et al.* 1990: fig. 8O. – Halamič & Goričan 1995: pl. 2, figs 18, 19. – Knipper *et al.* 1997: pl. 2, fig. 1.

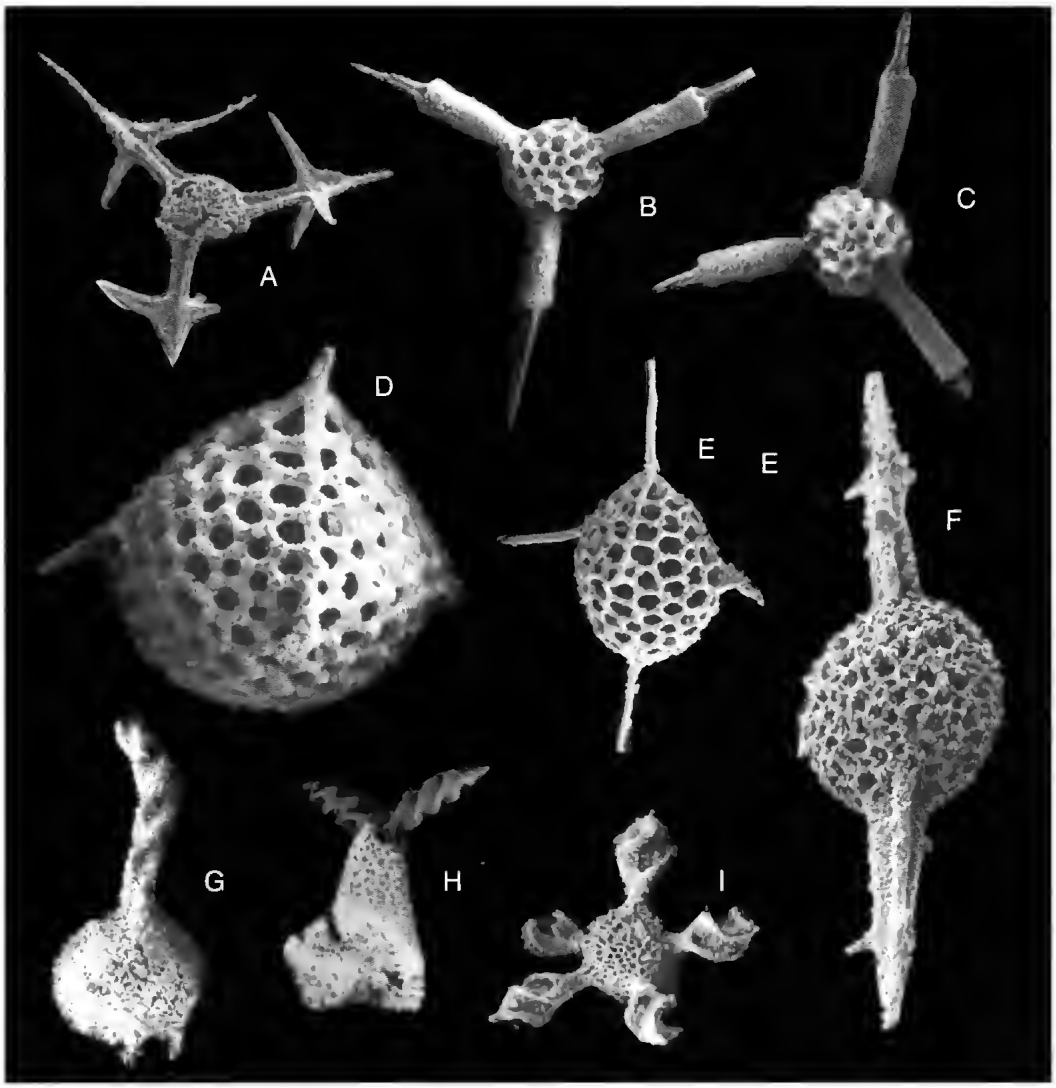

FIG. 7. — **A**, *Kahlerosphaera parvispinosa* Kozur & Mostler; **B**, **C**, *Capnodoce ruesti* Kozur & Mock; **D**, *Pentactinocarpus* sp. aff. *P. tetracanthus* Dumitrica; **E**, *Pentactinocarpus* sp.; **F**, *Spongostylus carnicus* Kozur & Mostler; **G**, *Karnospongella bispinosa* Kozur & Mostler; **H**, *Pentaspongodiscus* sp. 1; **I**, *Pseudostylosphaera* sp. Scale bar: A-C, E, G-I, 100 µm; D, F, 50 µm.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian, worldwide in the low paleolatitudes.

Spongostylus tortilis
Kozur & Mostler, 1979
(Fig. 8A)

Spongostylus tortilis Kozur & Mostler, 1979: 58, pl. 4, fig. 2; pl. 11, fig. 6; pl. 18, fig. 2; 1981: pl. 40, fig. 2; pl. 56, fig. 3. – Lahm 1984: 68, pl. 12, fig. 3.

Spongostylus sp. – Knipper *et al.* 1997: pl. 1, figs 5, 6.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian, worldwide in the low paleolatitudes.

Genus *Karnospongella*
Kozur & Mostler, 1981

TYPE SPECIES. — *Karnospongella bispinosa* Kozur & Mostler, 1981.

Karnospongella bispinosa
Kozur & Mostler, 1981
(Fig. 7G)

Spumellaria gen. *et* sp. indet. – Kozur & Mostler 1979: pl. 21, fig. 2.
Karnospongella bispinosa Kozur & Mostler, 1981: 42, pl. 50, figs 1, 2.
Gomberellus bispinosus (Kozur & Mostler) – Goričan et Bušer 1990: 146, pl. 1, fig. 10. – Halamič et Goričan 1995: pl. 1, fig. 6.
Karnospongella sp. B – Yeh 1989: pl. 14, fig. 16.
Bernoullius (?) *capricornus* – Bragin 1991b: 83, pl. 1, figs 1-5.

OCCURRENCE. — Middle to Upper Triassic, Ladinian to lower Norian, Tethys.

REMARKS
This finding represents the highest present-day known occurrence of *Karnospongella bispinosa* Kozur & Mostler.

Family FERRESIIDAE Carter, 1993

Genus *Ferresium* Blome, 1984

TYPE SPECIES. — *Ferresium laseekense* Blome, 1984.

Ferresium sp. aff. ***F. conclusum***
Carter, 1993
(Fig. 8B)

aff. *Ferresium conclusum* Carter, 1993: 68, pl. 9, figs 1-5.

REMARKS
This form differs from *F. conclusum* Carter by more strong torsion of main spines.

Family PATULIBRACCHIIDAE
Pessagno, 1971

Genus *Paronaella* Pessagno, 1971

TYPE SPECIES. — *Paronaella solanoensis* Pessagno, 1971a.

Paronaella norica Kozur & Mock, 1981
(Fig. 8G, H)

Paronaella norica Kozur & Mock, 1981 *in* Kozur & Mostler, 1981: 63, pl. 46, fig. 2.

OCCURRENCE. — Upper Triassic, Norian, worldwide in low paleolatitudes.

Paronaella sp.
(Fig 8I)

DESCRIPTION
Three-rayed spongy shell with short rays that have bulbous distal parts.

REMARKS
Due to poor preservation this form is difficult to compare with other representatives of genus *Paronaella*.

Genus *Triassocrucella* Kozur, 1984

TYPE SPECIES. — *Hagiastrum triassicum* Kozur & Mostler, 1978.

Triassocrucella triassica
(Kozur & Mostler, 1978)
(Fig. 8J)

Hagiastrum triassicum Kozur & Mostler, 1978: 144, pl. 1, fig. 4; pl. 2, fig. 11.
Crucella triassica (Kozur & Mostler) – Lahm 1984: 91, pl. 16, fig. 9.
Triassocrucella triassicum (Kozur & Mostler) – Kozur 1984: 33.

OCCURRENCE. — Upper Triassic, Carnian to Norian, European Tethys.

Superfamily PYLONIACEA Haeckel, 1881
Family ORBICULIFORMIDAE Pessagno, 1973

Genus *Praeorbiculiformella*
Kozur & Mostler, 1978

TYPE SPECIES. — *Praeorbiculiformella plana* Kozur & Mostler, 1978.

Praeorbiculiformella goestlingensis
Kozur & Mostler, 1978
(Fig. 8D)

Praeorbiculiformella goestlingensis Kozur & Mostler, 1978: 164, pl. 1, figs 10, 13; pl. 4, fig. 3. – Lahm 1984: 93, pl. 17, fig. 2.

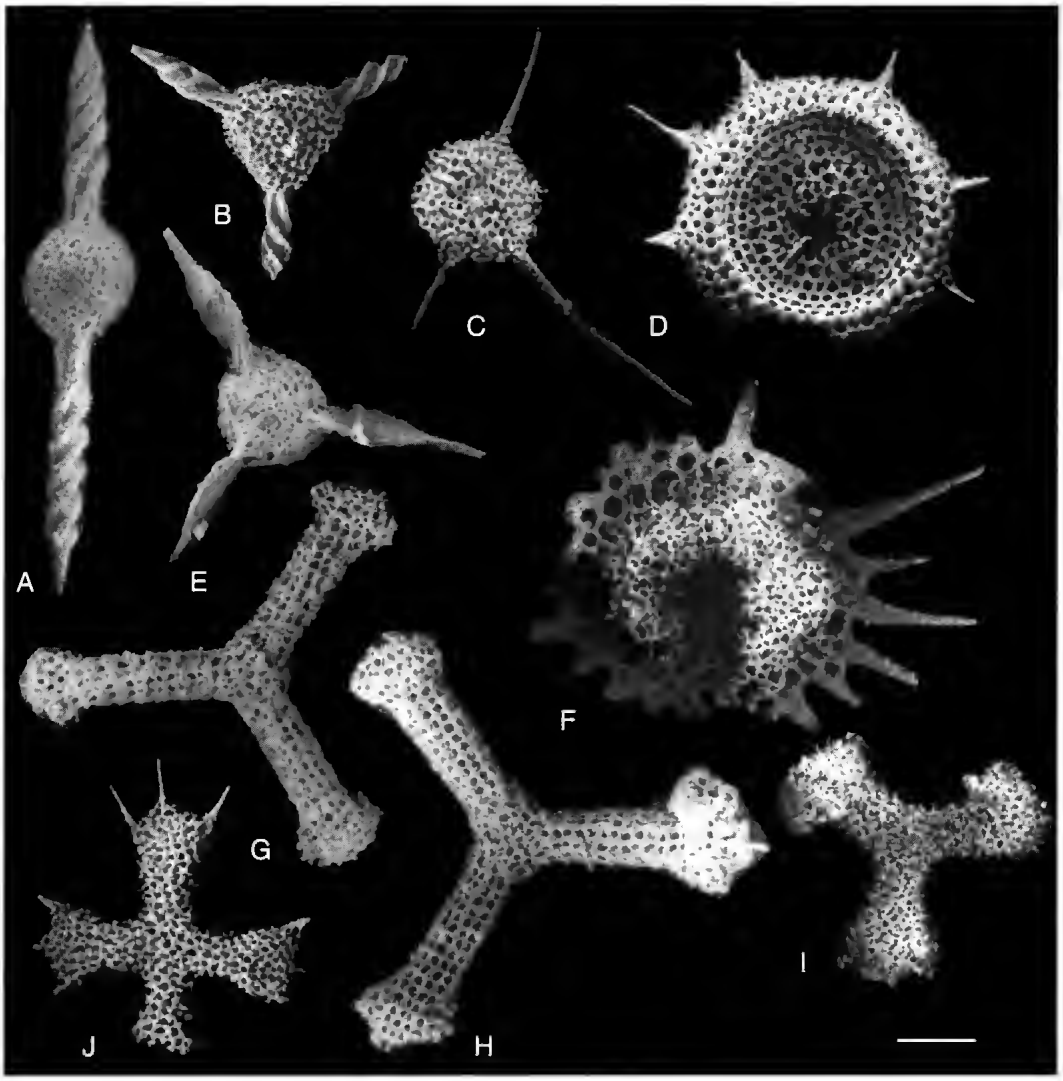

FIG. 8. — **A**, *Spongostylus tortilis* Kozur & Mostler; **B**, *Ferresium* sp. aff. *F. conclusum* Carter; **C**, *Pentaspongodiscus* sp. 2, **D**, *Praeorbiculiformella goestlingensis* Kozur & Mostler; **E**, *Zhamojdasphaera proceruspinosa* Lahn; **F**, *Veghicyclia* sp. cf. *V. robusta* Kozur & Mostler; **G**, **H**, *Paronaella norica* Kozur & Mock; **I**, *Paronaella* sp.; **J**, *Triassocrucella triassica* (Kozur & Mostler). Scale bar: A-H, J, 100 µm; I, 80 µm.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian, European Tethys.

Superfamily SATURNALIACEA
Deflandre, 1953
Family SATURNALIDAE Deflandre, 1953
Subfamily PARASATURNALINAE
Kozur & Mostler, 1972

Genus *Palaeosaturnalis* Donofrio & Mostler, 1978

TYPE SPECIES. — *Spongosaturnalis triassicus* Kozur & Mostler, 1972.

Palaeosaturnalis triassicus
(Kozur & Mostler, 1972)
(Fig. 9A, B, E)

Spongosaturnalis triassicus Kozur & Mostler, 1972: 40, pl. 1, fig. 10; pl. 4, figs 1, 2. – De Wever *et al.* 1979: 81, pl. 2, fig. 2.

Acanthocircus triassicus (Kozur & Mostler) – De Wever 1982: 207, pl. 13, fig. 10.
Palaeosaturnalis triassicus (Kozur & Mostler) – Lahm 1984: 97, pl. 17, fig. 11.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian, Tethys.

Palaeosaturnalis mocki
Kozur & Mostler, 1983
(Fig. 9G, H)

Palaeosaturnalis mocki Kozur & Mostler, 1983: 21, pl. 5, fig. 2.

OCCURRENCE. — Upper Triassic, lower Norian, Carpathians, Cyprus.

Palaeosaturnalis latiannulatus
Kozur & Mostler, 1983
(Fig. 9D)

Palaeosaturnalis latiannulatus Kozur & Mostler, 1983: 20, pl. 5, fig. 1.

OCCURRENCE. — Upper Triassic, lower Norian, Carpathians, Cyprus.

Genus *Liassosaturnalis*
Kozur & Mostler, 1990

TYPE SPECIES. — *Liassosaturnalis parvus* Kozur & Mostler, 1990.

Liassosaturnalis parvus
Kozur & Mostler, 1990
(Fig. 9C)

Liassosaturnalis parvus Kozur & Mostler, 1990: 203, pl. 4, figs 3, 7, 12, pl. 6, fig. 6.

OCCURRENCE. — Upper Triassic (Norian) to Lower Jurassic (Hettangian) of the European Tethys.

Genus *Praemesosaturnalis*
Kozur & Mostler, 1981

TYPE SPECIES. — *Spongosaturnalis bifidus* Kozur & Mostler, 1972.

Praemesosaturnalis sp.
cf. ***P. multidentatus***
(Kozur & Mostler, 1972)
(Fig. 9F)

cf. *Spongosaturnalis multidentatus* Kozur & Mostler, 1972: 38, pl. 1, fig. 20.

DESCRIPTION
Ring with two peripolar short main spines, with numerous very small auxiliary spines, and with eleven short outer rays. Main spines asymmetrically arranged.

REMARKS
This form differs from typical *P. multidentatus* (Kozur & Mostler) by the asymmetrical arrangement of main spines and by shorter outer rays.

Genus *Veghicyclia*
Kozur & Mostler, 1972

TYPE SPECIES. — *Veghicyclia pulchra* Kozur & Mostler, 1972.

Veghicyclia sp. cf. ***V. robusta***
Kozur & Mostler, 1972
(Fig. 8F)

cf. *Veghicyclia robusta* Kozur & Mostler, 1972: 15, pl. 3, figs 1, 4, 7.

REMARKS
This form has poorly preserved central part. It possesses longer and thinner rays than typical *V. robusta*.

SPUMELLARIINA incertae familiae

Genus *Pentaspongodiscus*
Kozur & Mostler, 1979

TYPE SPECIES. — *Pentaspongodiscus tortilis* Kozur & Mostler, 1979.

Pentaspongodiscus sp. 1
(Fig. 7H)

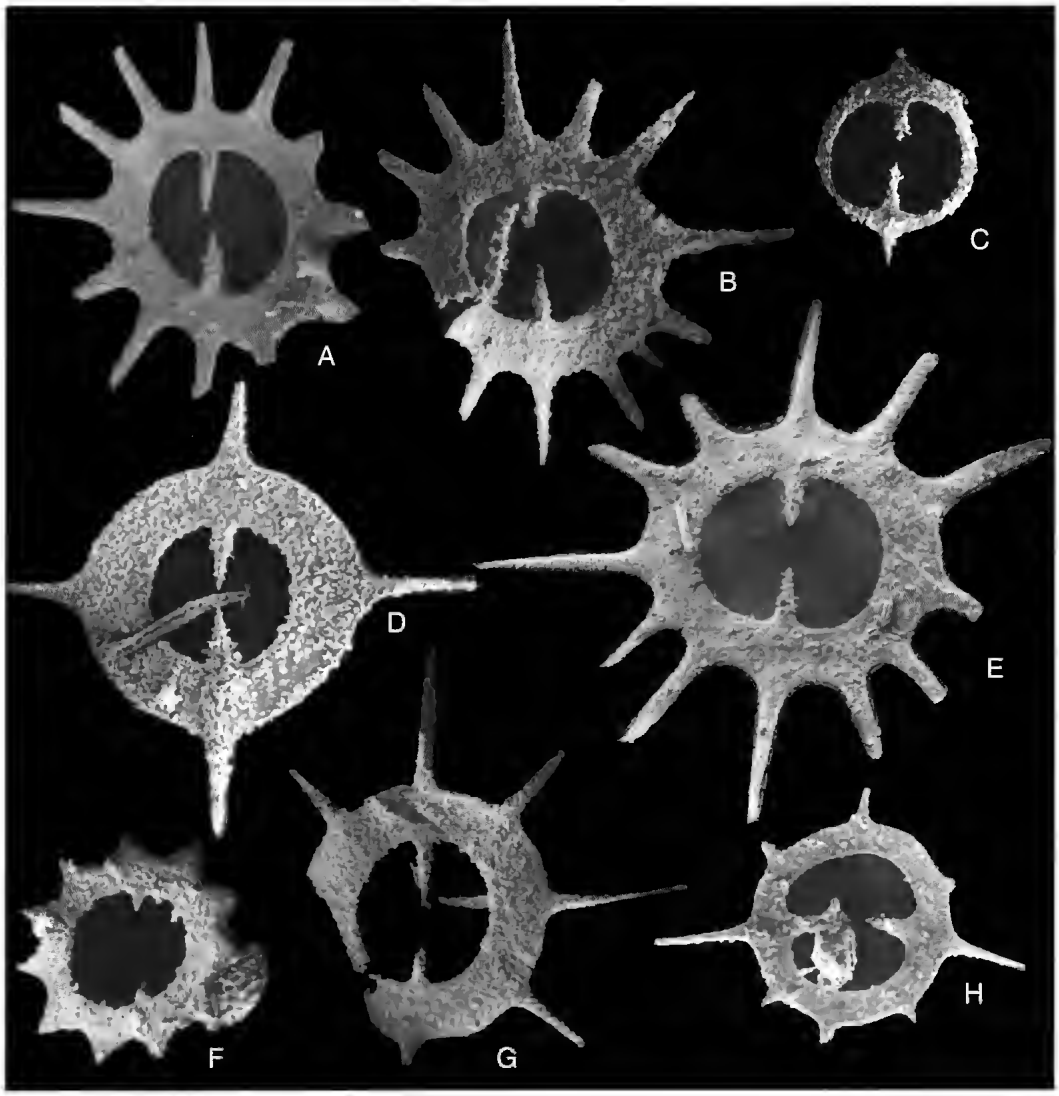

FIG. 9. — **A**, **B**, **E**, *Palaeosaturnalis triassicus* (Kozur & Mostler); **C**, *Liassosaturnalis parvus* Kozur & Mostler; **D**, *Palaeosaturnalis latiannulatus* Kozur & Mostler; **F**, *Praemesosaturnalis* sp. cf. *P. multidentatus* (Kozur & Mostler); **G**, **H**, *Palaeosaturnalis mocki* Kozur & Mostler. Scale bar: 100 µm.

DESCRIPTION

Shell small, flattened, discoidal, with five main spines. Spines short, thick, spindle-shaped, with Y-shaped cross-section and strong dextral torsion.

REMARKS

This form differs from other representatives of genus *Pentaspongodiscus* Kozur & Mostler by the spindle-shaped thick spines with strong torsion.

Pentaspongodiscus sp. 2
(Fig. 8C)

REMARKS

The illustrated specimen is uncomplete. It has probably six very thin spines.

Order NASSELLARIA Ehrenberg, 1875
Family POULPIDAE De Wever, 1981

Genus *Poulpus* De Wever, 1979

TYPE SPECIES. — *Poulpus piabyx* De Wever, 1979.

Poulpus piabyx De Wever, 1979
(Fig. 10A-C)

Poulpus piabyx De Wever, 1979: 98, pl. 7, figs 12, 13. – Kozur & Mostler 1979: 89, pl. 4, fig. 3. – De Wever 1982: 328, pl. 48, figs. 5, 6. – Yeh 1990: pl. 8, figs 3, 7, 9. – Sugiyama 1997: fig. 49 (15).

OCCURRENCE. — Upper Triassic, upper Carnian to lower Norian, worldwide in the low-paleolatitudes.

Genus *Neopylentonema* Kozur, 1984

TYPE SPECIES. — *Neopylentonema mesotriassica* Kozur, 1984.

Neopylentonema sp.
aff. ***N. procera*** Sugiyama, 1997
(Fig. 10E)

? *Poulpus* (?) sp. *C* – Yeh 1989: 74, pl. 6, figs 5, 10.
aff. *Neopylentonema procera* Sugiyama, 1997: 161, figs 46-3a, b.

REMARKS
This form has longer and thinner apical spine and three feet than typical *N. procera*. It is more similar to *Poulpus* sp. C (Yeh 1989). Only a few specimens were obtained, mostly poorly preserved.

Family FOREMANELLIDAE Dumitrica, 1982

Genus *Foremanellina* Dumitrica, 1982

TYPE SPECIES. — *Foremanellina helenae* Dumitrica, 1982.

Foremanellina **(?)** sp.
(Fig. 10J)

DESCRIPTION
Small form with three-bladed apical horn and three lateral horns, slightly inclined downwards.

REMARKS
This form has poor preservation and cannot be determined on the species level.

Family PSEUDOSATURNIFORMIDAE
Kozur & Mostler, 1979

Genus *Pseudosaturniforma*
Kozur & Mostler, 1979

TYPE SPECIES. — *Pseudosaturniforma latimarginata* Kozur & Mostler, 1979.

Pseudosaturniforma carnica
Kozur & Mostler, 1979
(Fig. 10I, K, L)

Pseudosaturniforma carnica Kozur & Mostler, 1979: 94, pl. 17, fig. 3; 1981: pl. 22, fig. 3.

OCCURRENCE. — Upper Triassic, Carnian to lower Norian of European Tethys.

Family ULTRANAPORIDAE Pessagno, 1977

Genus *Trialatus* Yeh, 1990

TYPE SPECIES. — *Trialatus megacornutus* Yeh, 1990.

Trialatus robustus
(Nakaseko & Nishimura, 1979)
(Fig. 11A, B)

Napora robusta Nakaseko & Nishimura, 1979: 78, pl. 8, figs 4-6. – Yoshida 1986: pl. 7, figs 1, 6, 8. – Bragin 1991a: 97, pl. 6, figs 2, 3.
Trialatus robustus (Nakaseko & Nishimura) – Sugiyama 1997: fig. 27 (16).

OCCURRENCE. — Upper Triassic, upper Carnian to lower Norian, Japan, eastern Russia and Cyprus.

REMARKS
Specimens obtained from Cyprus differ from typical by the presence of an additional postthoracic segment. This segment (abdomen?) has subtrapezoidal outline and very thin latticed wall. Common specimens from Japan and eastern Russia were obtained from cherts and did not represent this element, probably due to the preservation.

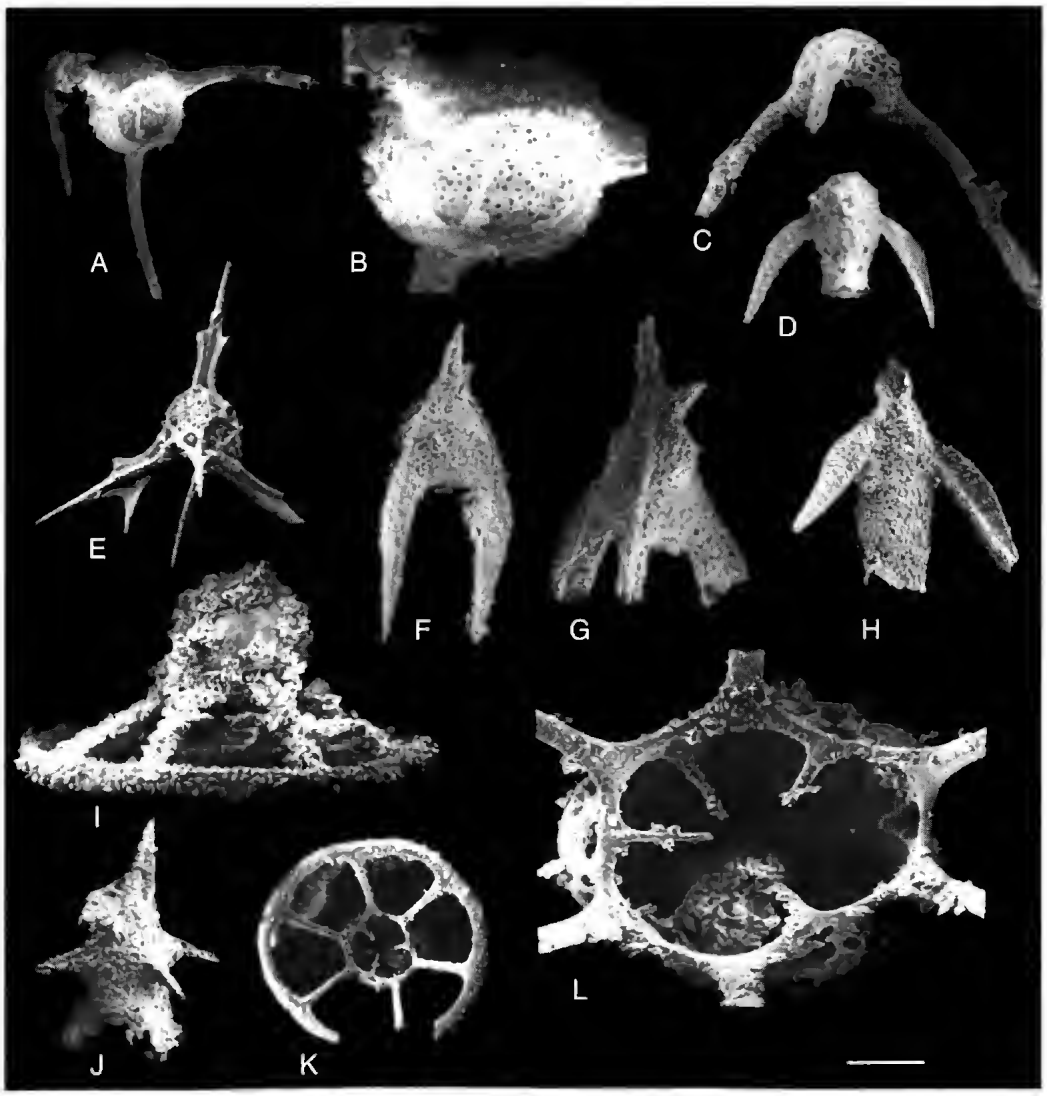

FIG. 10. — **A-C**, *Poulpus piabyx* De Wever; **D**, **H**, *Triassobipedis* (?) sp.; **E**, *Neopylentonema* sp. aff. *N. procera* Sugiyama; **F**, *Napora* (?) sp. 1; **G**, *Napora* (?) sp. 2; **I**, **K**, **L**, *Pseudosaturniforma carnica* Kozur & Mostler; **J**, *Foremanellina* (?) sp. Scale bar: A, D-H, J, K, 100 µm; B, 35 µm; C, 80 µm; I, 50 µm; L, 20 µm.

Genus *Napora* Pessagno, 1977

TYPE SPECIES. — *Napora bukryi* Pessagno, 1977.

Napora **(?)** sp. 1
(Fig. 10F)

DESCRIPTION
Small subconical test with short thin three-bladed apical horn and three long, straight three-bladed feet. Very short and thin inclined vertical horn can be seen at apical part.

REMARKS
Only one specimen was obtained and illustrated.

Napora **(?)** sp. 2
(Fig. 10G)

DESCRIPTION
Small test with apical horn and three feet.

Cephalis dome-shaped with moderately long slightly inclined apical horn and small inclined vertical horn. Thorax hemispherical, inflated, with numerous small pores. Feet moderately long, strongly flattened.

REMARKS
Only one specimen of imperfect preservation was found.

Family BULBOCYRTIDAE
Kozur & Mostler, 1981

Genus *Bulbocyrtium* Kozur & Mostler, 1981

TYPE SPECIES. — *Bulbocyrtium reticulatum* Kozur & Mostler, 1981.

Bulbocyrtium latum Bragin n. sp.
(Fig. 11I, J)

Bulbocyrtium aff. *reticulatum* Kozur & Mostler – Carter *et al.* 1989: pl. 1, fig. 1.

HOLOTYPE. — Fig. 11J, GIN-4858-23, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — Latus (Latin), broad.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DIMENSIONS (based on three specimens). — Length of test without apical horn 260-320 µm, width of cephalis 165-175 µm, maximal width of test 280-340 µm, length of apical horn 80 µm.

DESCRIPTION
Test with four chambers. Cephalis large, spherical with thin three-bladed apical horn. Cephalis surface with network-like system of small nodes connected by thin ridges that form polygonal framework. Pores of cephalis small, subcircular, irregularly arranged. Thorax subcylindrical, more than twice shorter than cephalis. Abdomen subcylindrical to subtrapezoidal. Postabdominal segment with expanded termination and wide open aperture. Height of all postcephalic segments less than of cephalis. Small strictures are developed between cephalis, thorax and abdomen. Pores of postcephalic segments small, subcircular, irregularly arranged.

REMARKS
Bulbocyrtium latum Bragin n. sp., differs from *B. reticulatum* (Kozur & Mostler 1981: 106, pl. 11, fig. 1) by larger cephalis with finer network-like surface and by wider last segment.

Family DEFLANDRECYRTIDAE
Kozur & Mostler, 1979

Genus *Caphtorocyrtium* Bragin n. gen.

TYPE SPECIES. — *Caphtorocyrtium tenerum* n. sp.

SPECIES INCLUDED. — *Caphtorocyrtium tenerum* Bragin n. sp.

ETYMOLOGY. — Caphtorim-Biblic name; ancestor of Cypriots.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DESCRIPTION
Dicyrtid (or tricyrtid) form with small cephalis, large, conical postcephalic part, with an apical horn and three lateral horns.

REMARKS
Caphtorocyrtium n. gen. differs from *Deflandrecyrtium* (Kozur & Mostler, 1979: 98) by the presence of lateral horns. Genus *Planispinocyrtis* (Kozur & Mostler, 1981: 111) has multicyrtoid test. It is very difficult to conclude how many segments this genus has (two or three). Due to replacement by pyrite, the inner structure of apical part cannot be observed. Nevertheless, conical distal part of test has open aperture and represents one segment (thorax or abdomen).

Caphtorocyrtium tenerum Bragin n. sp.
(Fig. 11C-H)

HOLOTYPE. — Fig. 11F, GIN-4858-71, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — Tener (Latin), tender.

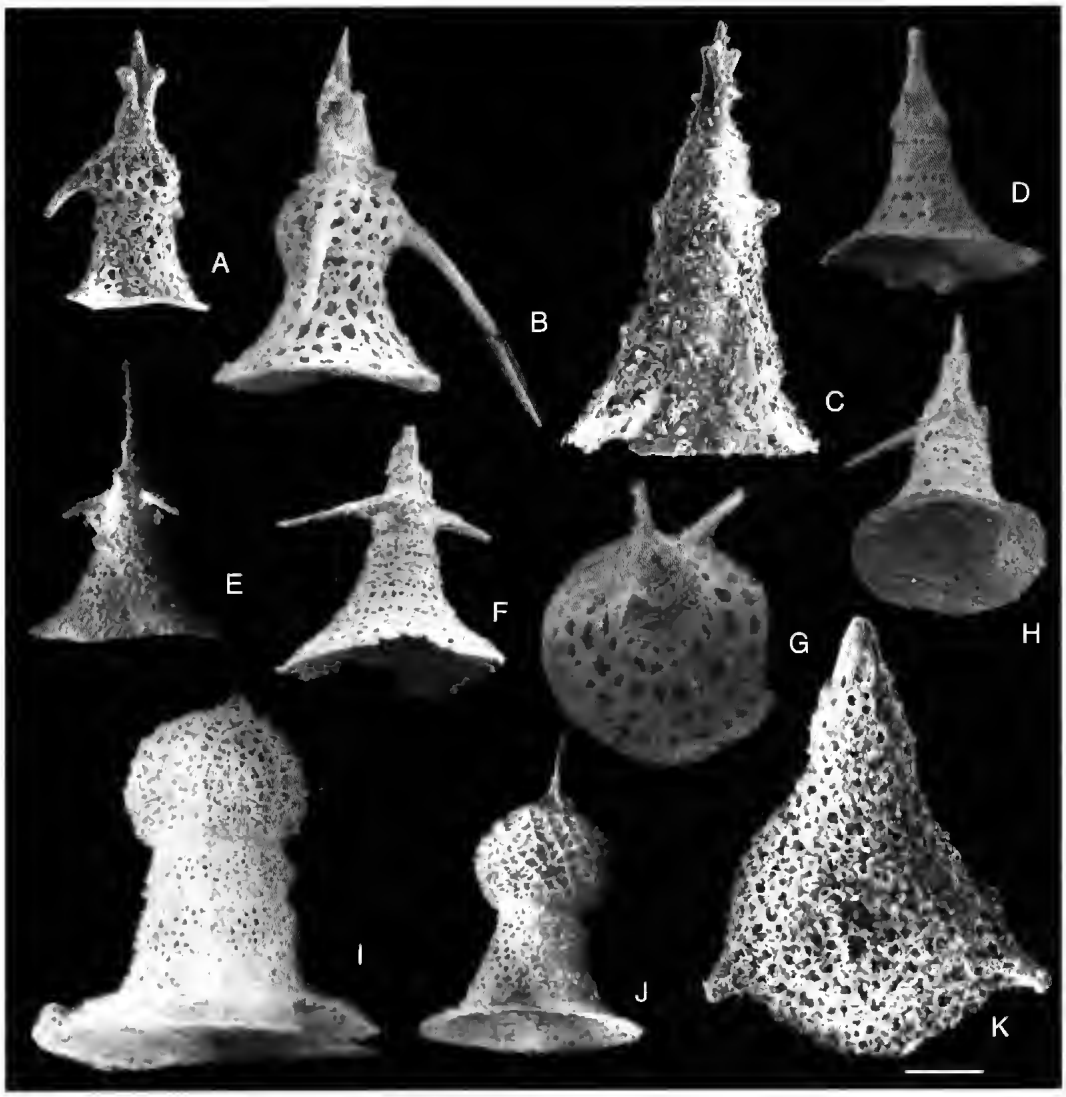

FIG. 11. — **A**, **B**, *Trialatus robustus* (Nakaseko & Nishimura); **C-H**, *Caphtorocyrtium tenerum* Bragin n. gen., n. sp.; **F**, holotype; **I**, **J**, *Bulbocyrtium latum* Bragin n. sp.; **J**, holotype; **K**, *Sethocapsa* (?) sp. Scale bar: A, D-H, J, 100 µm; B, I, 80 µm; C, K, 35 µm.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DIMENSIONS (based on eleven specimens). — Length of test including apical horn 290-335 µm, maximal width of test 235-290 µm.

DESCRIPTION

Dicyrtid or tricyrtid form. Cephalis small, poreless, conical with long thin rod-like apical horn and three lateral horns as prolongations of D and L (?). Lateral horns thin, long, rod-like, slightly inclined distally. Postcephalic part large, conical to concave-conical with 5-6 transversal rows of subcircular to subrectangular pores, variable in size. Width of postcephalic part rapidly increasing distally, aperture wide, open.

Family NEOSCIADIOCAPSIDAE Pessagno, 1969

Genus *Haeckelicyrtium* Kozur & Mostler, 1979

TYPE SPECIES. — *Haeckelicyrtium austriacum* Kozur & Mostler, 1979.

REMARKS
Following Sugiyama (1997) the two-chambered hat-like Triassic nassellarians, which belong to neither *Deflandrecyrtium* Kozur & Mostler, 1979 nor *Dreyericyrtium* Kozur & Mostler, 1979 and have no basal feet, are assigned to genus *Haeckelicyrtium* Kozur & Mostler.

Haeckelicyrtium carterae Bragin n. sp. (Fig. 12A-C, E, F)

HOLOTYPE. — Fig. 12A, GIN-4858-79, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — New species is named after Dr. Elisabeth Carter in honour of her contributions to Mesozoic Radiolaria.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DIMENSIONS (based on seven specimens). — Length of test without apical horn 190-235 µm, maximal length of apical horn 400 µm (Fig. 12E), maximal width of test 265-490 µm.

DESCRIPTION
Cephalis small subconical with long thin rod-like apical horn. Thorax large with hemispherical inflated proximal part and with strongly expanded distal part with a broad thoracic skirt. Cephalis and thorax single-layered with circular pores enlarging distally and arranged into hexagonal framework. Pores of thoracic skirt large, subspherical. Velum not developed, aperture large, open.

REMARKS
Haeckelicyrtium carterae Bragin n. sp. differs from *H. teren* Sugiyama, 1997 by inflated proximal part of thorax, well-developed stricture between thorax and thoracic skirt and by very long and thin apical horn.

Genus *Nabolella* Petrushevskaya, 1981

TYPE SPECIES. — *Squinabolella longispinosa* Kozur & Mostler, 1979.

REMARKS
According to the original definition (Petrushevskaya 1981: 76) only two-chambered hat-like forms with basal feet are assigned to this genus.

Nabolella trispinosa Bragin n. sp. (Fig. 12D, G-I)

HOLOTYPE. — Fig. 12G, H, GIN-4858-82, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — By the presence of three basal feet.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DIMENSIONS (based on three specimens). — Length of test without apical horn and basal feet 180-200 µm, maximal width of test 290-300 µm, length of apical horn 100 µm.

DESCRIPTION
Cephalis dome-like with long thin rod-like slightly inclined apical horn and small indistinct pores. Distinctive stricture is developed between cephalis and thorax. Thorax hat-like with inflated proximal part and wide skirt-like distal part. Wall of thorax single, latticed with subcircular pores increasing distally. Median part of thorax with deep stricture. Three long rod-like spines begin from cephalis and are partly incorporated into thoracic wall. Their distal parts form three basal feet. Spines can be supposed as prolongations of D and L. Velum not developed.

REMARKS
This species differs from *Nabolella longispinosa* (Kozur & Mostler, 1979) having only three basal feet.

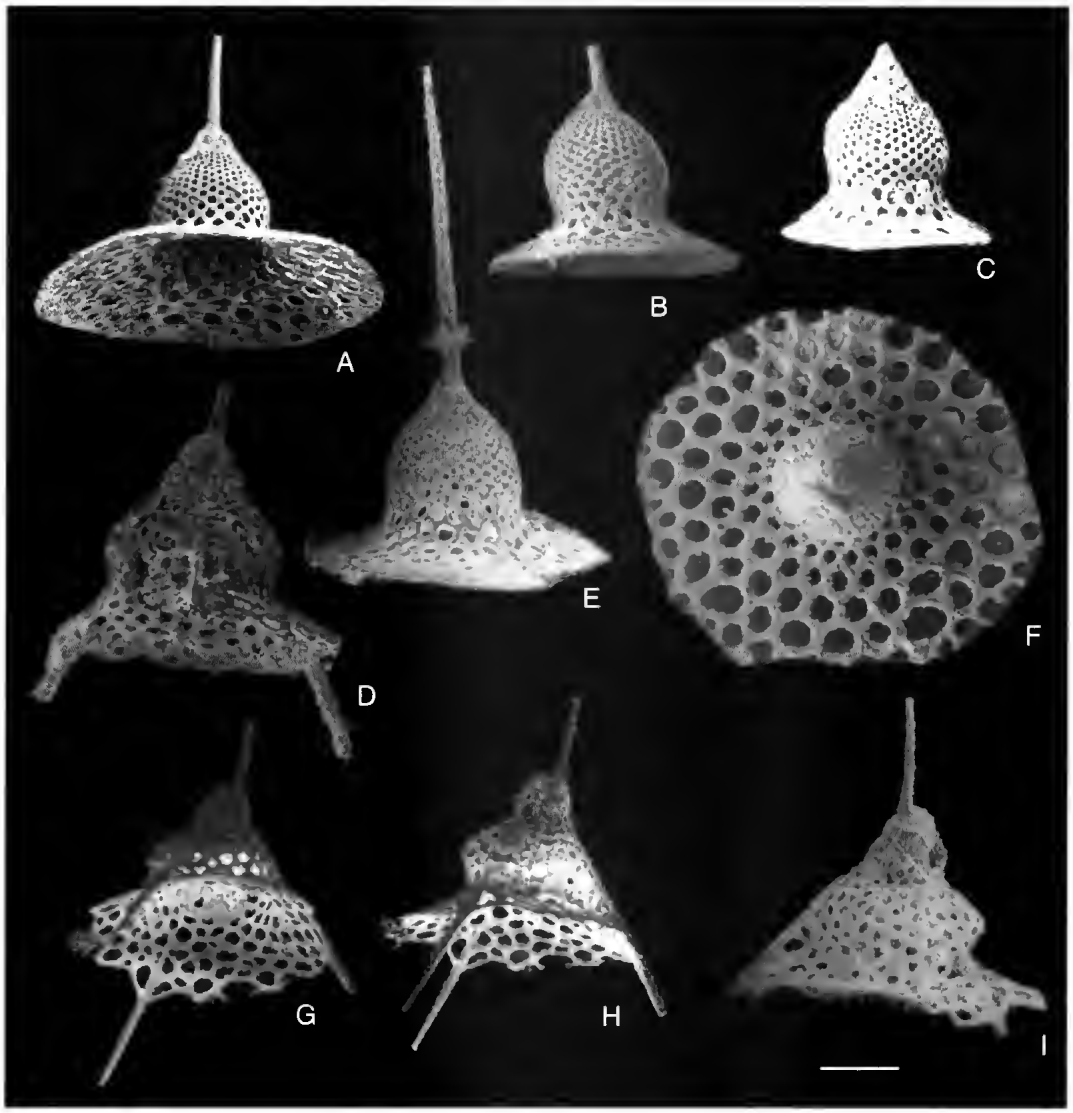

FIG. 12. — **A-C, E, F,** *Haeckelicyrtium carterae* Bragin n. sp.; **A**, holotype; **D, G-I,** *Nabolella trispinosa* Bragin n. sp.; **G, H,** holotype. Scale bar: 100 µm.

Family SYRINGOCAPSIDAE Foreman, 1973

Genus *Syringocapsa* Neviani, 1900

TYPE SPECIES. — *Theosyringium robustum* Vinassa, 1901.

Syringocapsa batodes De Wever, 1979
(Fig. 13L, M)

Syringocapsa batodes De Wever, 1979: 91, pl. 6, figs 10, 12. – Nakaseko & Nishimura 1979: 81, pl. 8, figs 9, 10. – De Wever 1982: 292, pl. 41, figs 13, 14; pl.42, fig. 6.
Syringocapsa cf. *batodes* De Wever – Yoshida 1986: pl. 6, fig. 9, 10.
? unnamed *Podobursa*-like nassellarian – Pessagno *et al.* 1979: pl. 4, fig. 7.

OCCURRENCE. — Upper Triassic, upper Carnian to lower Norian, worldwide in the low-palaeolatitude regions.

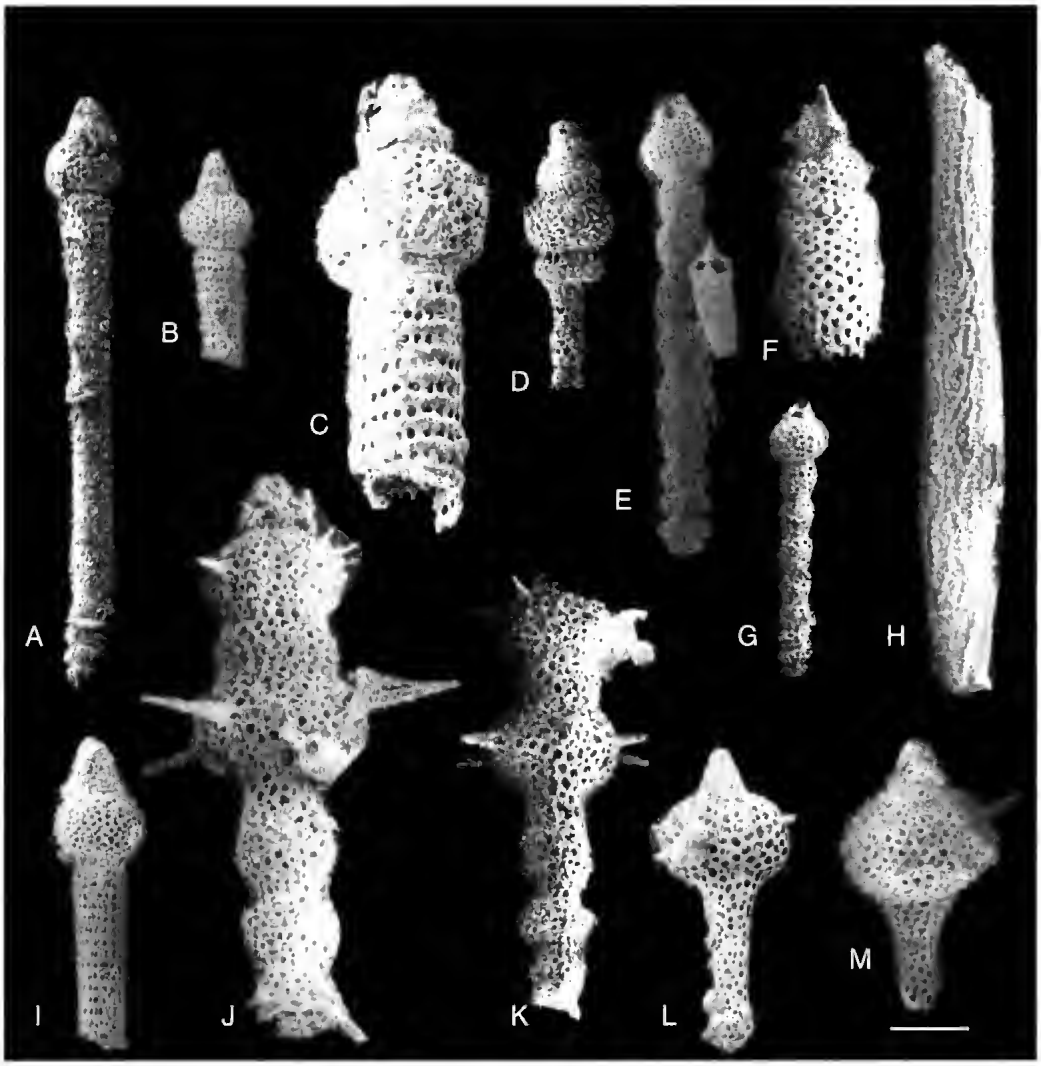

FIG. 13. — **A-C, I**, *Xiphotheca rugosa* Bragin; **D**, *Xiphotheca* sp.; **E, G**, *Xiphotheca longa* Kozur & Mock; **F**, Nassellaria gen. et sp. indet.; **H**, *Xiphotheca* (?) sp.; **J, K**, *Xiphotheca* (?) *spinellifera* Bragin n. sp.; **J**, holotype; **L, M**, *Syringocapsa batodes* De Wever. Scale bar: A, B, D-M, 100 µm; C, 35 µm.

Syringocapsa sp.
(Fig. 14I)

DESCRIPTION

Test small, with subconical apical part, subspherical, inflated middle part and distal part that tends to be tubular (incompletely preserved). Apical part poreless, with tiny, very short apical horn. Middle part with numerous circular pores in rectangular pore frames with sharp nodes at vertices, with occasional short spines.

REMARKS

This form cannot be compared or described as new taxon due to uncomplete preservation.

Family PSEUDODICTYOMITRIDAE Pessagno, 1977b

Genus *Whalenella* Kozur, 1984

TYPE SPECIES. — *Dictyomitra arrecta* Hinde, 1908.

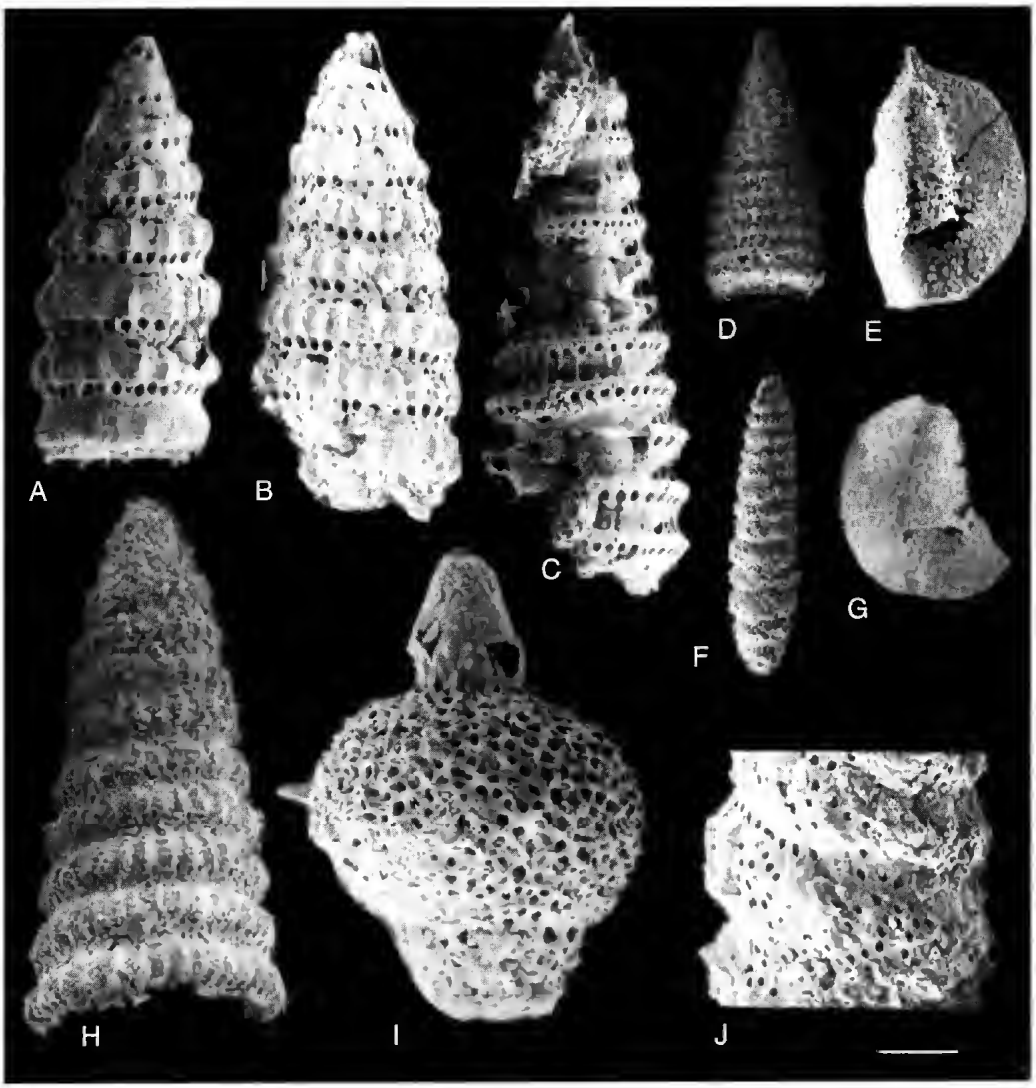

FIG. 14. — **A**, **B**, *Whalenella robusta* Bragin n. sp.; **A**, holotype; **C**, *Annulotriassocampe* sp. cf. *A. sulovensis* (Kozur & Mock); **D**, *Multimonilis pulcher* Yeh; **E**, **G**, Triassocampidae gen. et sp. indet.; **F**, **J**, *Laxtorum* (?) sp.; **H**, *Whalenella* sp. aff. *W. perfecta* Blome; **I**, *Syringocapsa* sp. Scale bar: A-C, H-J, 35 µm; D-G, 100 µm.

Whalenella sp.
aff. *W. perfecta* (Blome, 1984)
(Fig. 14H)

aff. *Corum perfectum* Blome, 1984: pl. 13, figs 2, 7, 16; pl. 17, fig. 11.

REMARKS

This form differs from *Whalenella perfecta* (Blome) by larger number of chambers (twelve *vs* seven). Other external morphological features are very similar. There are discontinuous costae and single row of small pores at each postabdominal chamber.

Whalenella robusta Bragin n. sp.
(Fig. 14A, B)

HOLOTYPE. — Fig. 14A, GIN-4858-12, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — Robustus (Latin), strong, stout.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DIMENSIONS (based on five specimens). — Length of test 180-205 µm, maximal width of test 85-90 µm.

DESCRIPTION
Test multicyrtoid with 8-9 chambers. Cephalis poreless, dome-shaped, without apical horn. Thorax subtrapezoidal, smooth. Abdomen and postabdominal chambers with well-developed smooth discontinuous costae. Chambers of the middle part of the test have 16-18 costae (8-9 visible). Each chamber has single row of large, deep, circular to slightly elliptical pores. Height of chambers increases very slowly. Width of chambers increases to the fourth postabdominal chamber, then becomes constant or slightly decreasing.

REMARKS
This species differs from *Whalenella speciosa* (Blome, 1984) by less inflated, smooth costae that did not merge at final chambers, and by larger pores.

Genus *Multimonilis* Yeh, 1989

TYPE SPECIES. — *Multimonilis pulcher* Yeh, 1989.

Multimonilis pulcher Yeh, 1989
(Fig. 14D)

Multimonilis pulcher Yeh, 1989: 72, pl. 9, figs 9, 19.

OCCURRENCE. — Upper Triassic, upper Carnian-lower to middle Norian of Oregon and Cyprus.

Family TRIASSOCAMPIDAE
Kozur & Mostler, 1981

Genus *Annulotriassocampe* Kozur, 1994

TYPE SPECIES. — *Annulotriassocampe baldii* Kozur, 1994.

Annulotriassocampe sp.
cf. ***A. sulovensis*** (Kozur & Mock, 1981)
(Fig. 14C)

cf. *Triassocampe sulovensis* Kozur & Mock, *in* Kozur & Mostler, 1981: 99, pl. 13, fig. 3. – Yeh 1989: 76, pl. 2, fig. 13.

REMARKS
Only a few poorly preserved specimens were found.

Triassocampidae gen. *et* sp. indet.
(Fig. 14E, G)

DESCRIPTION
Test multicyrtoid, small. Cephalis dome-shaped, with indistinct pores, with thin apical horn. Test has 5-6 segments, the last ones with transversal rows of small pores. A flat, leaf-like extension begins from the proximal part of the apical horn and surrounds test as wide ellipsoidal ring. Two sides of ring form an angle (120°).

REMARKS
Only a few imperfect specimens were found.

Family SETHOCAPSIDAE Haeckel, 1881

Genus *Sethocapsa* Haeckel, 1881

TYPE SPECIES. — *Sethocapsa cometa* (Pantanelli, 1885).

Sethocapsa **(?)** sp.
(Fig. 11K)

DESCRIPTION
Test small. Cephalis poreless, dome-shaped, thorax subtrapezoidal with few pores between several longitudinal smooth ridges. Postabdominal part of test inflated with spongy wall and five to six (?) short basal feet. Aperture indistinct, might be closed.

REMARKS
This species is very rare in studied material.

NASSELLARIA incertae familiae

Genus *Xiphotheca* De Wever, 1979

TYPE SPECIES. — *Xiphotheca karpenissionensis* De Wever, 1979.

Xiphotheca rugosa Bragin, 1991
(Fig. 13A-C, I)

Xiphotheca rugosa Bragin, 1991a: 107, pl. 5, fig. 11, 13.

OCCURRENCE. — Upper Triassic, upper Carnian to lower Norian of eastern Russia and Cyprus.

Xiphotheca longa Kozur & Mock, 1981
(Fig. 13E, G)

Xiphotheca longa Kozur & Mock, *in* Kozur & Mostler, 1981: 113, pl. 41, fig. 2.

OCCURRENCE. — Upper Triassic, lower Norian of European Tethys.

Xiphotheca (?) *spinellifera* Bragin n. sp.
(Fig. 13J, K)

HOLOTYPE. — Fig. 13J, GIN-4858-3, Cyprus, Agia Varvara Village, Mamonia Complex, Upper Triassic, lower Norian.

ETYMOLOGY. — Spinellifera (Latin), wearing small spines.

OCCURRENCE. — Upper Triassic, lower Norian, Cyprus.

DIMENSIONS (based on three specimens). — Length of test 700 µm, maximal width of abdomen 150-180 µm, maximal width of the second postabdominal chamber without equatorial spines 165-225 µm.

DESCRIPTION
Test large, very long, multicyrtoid. Cephalis small, dome-like. Thorax small, hemispherical. Cephalis and thorax without distinct pores. Abdomen large, inflated, with equatorially arranged thin short spines. First postabdominal segment twice smaller than abdomen, without spines. Second postabdominal chamber larger than abdomen, inflated, with equatorially arranged spines that are longer and thicker than spines of abdomen. Three last postabdominal chambers smaller than abdomen, moderately inflated, without equatorial spines. Last segment with small spines around open, small, subcircular aperture. All postthoracic segments with small subcircular pores in polygonal irregular pore frames.

REMARKS
Xiphotheca (?) *spinellifera* Bragin n. sp. differs from other described species of *Xiphotheca* De Wever by the presence of equatorial spines and by strong inflation of the second postabdominal segment. This form differs from representatives of *Syringocapsa* Neviani by well-developed segmentation of postabdominal part. The taxonomic positions of *Xiphotheca* (?) *spinellifera* Bragin n. sp. is still unclear.

Xiphotheca sp.
(Fig. 13D)

REMARKS
This form has strongly inflated first postabdominal chamber. The tubular part of test begins from the third postabdominal chamber.

Xiphotheca (?) sp.
(Fig. 13H)

REMARKS
Only long fragments of tube without apical part were found. Tube without segmentation, with very small pores and thin longitudinal curved and bifurcated ridges is very characteristic and unknown among other representatives of *Xiphotheca* De Wever.

Genus *Laxtorum* Blome, 1984

TYPE SPECIES. — *Laxtorum hindei* Blome, 1984.

Laxtorum (?) sp.
(Fig. 14F, J)

DESCRIPTION
Test multicyrtoid, spindle-shaped. Cephalis small, dome-shaped, poreless, smooth. Thorax subtrapezoidal, poreless, smooth. Postthoracic segments short, inflated, divided each from other by well-developed deep and narrow strictures. Width of segments slowly increasing up to the tenth segment and become decreasing at the distal part of test. Each postthoracic segment has

numerous small circular pores. They form single transversal row at strictures between segments.

REMARKS
This form differs from other representatives of genus *Laxtorum* by absence of apical horn and weak development of pores.

Genus *Triassobipedis* Kozur, 1984

TYPE SPECIES. — *Triassobipedis balatonica* Kozur, 1984.

Triassobipedis **(?)** sp.
(Fig. 10D, H)

REMARKS
These small forms have two basal feet like representatives of genera *Triassobipedis* Kozur and *Bipedis* De Wever. They have characteristic tubular distal part of test that is sometimes longer than basal feet. Both illustrated specimens have imperfect preservation. Character of cephalic structure and segmentation of test are unclear.

Nassellaria gen. *et* sp. indet.
(Fig. 13F)

DESCRIPTION
Test multicyrtoid. Cephalothorax subconical, smooth, without stricture between cephalis and thorax, with apical horn and three lateral horns. All horns short and smooth. Abdomen inflated, subspherical, divided from thorax by deep stricture. Postabdominal part subcylindrical. Abdomen and postabdominal part with numerous subcircular pores enclosed in hexagonal to pentagonal pore frames.

REMARKS
Only few specimens were found. They did not show affinity with any Triassic form described before.

Acknowledgements
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Cuboctostylus n. gen., a new Late Cretaceous spicule-bearing spumellarian Radiolaria from southern Sakhalin (Russia)

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ABSTRACT

A new spicule-bearing genus of Spumellaria (Radiolaria) *Cuboctostylus*, and three new species – *Cuboctostylus kasinzovae*, *C. sakhalinensis*, and *C. trifurcatus*, are described from the Late Cretaceous deposits of Sakhalin (Russia). This genus has many characters in common with the Lower-Middle Cretaceous genus *Pyloctostylus* Dumitrica, from which it differs essentially in having no pylome and the spicule centrally placed. The genus has also some characters in common with the Paleozoic family Polyentactiniidae and the Cenozoic family Orosphaeridae.

KEY WORDS
Radiolaria,
Entactinaria,
systematics,
new taxa,
Upper Cretaceous,
Sakhalin,
spicule.

RÉSUMÉ

Cuboctostylus *n. gen., genre nouveau de spumellaires à spicule initial du Cretacé supérieur, Sakhaline du Sud (Russie).*

Le nouveau genre de spumellaires (radiolaires) *Cuboctostylus* et trois nouvelles espèces – *C. kasinzovae*, *C. sakhalinensis*, *C. trifurcatus* sont décrit dans les sédiments du Crétacé supérieut, Sakhaline du Sud, Russie. Ce taxon nouveau est très proche du genre *Pyloctostylus* Dumittica du Cretacé infétieur-moyen, mais il en diffère principalement par l'absence du pylome et par la localisation du spicule dans la zone centrale. Le gente rappelle aussi les représentants de la famille paléozoïque Polyentactiniidae et de la famille cénozoïque Orosphaeridae.

MOTS CLÉS
Radiolaria,
Entactinaria,
systématique,
nouveaux taxons,
Cretacé supérieur,
Sakhaline,
spicule.

INTRODUCTION

The spicule-bearing Spumellaria are common in the Paleozoic (Foreman 1963; Nazarov 1975, 1988; Isakova & Nazarov 1986) and Triassic (Dumitrica 1978; Dumitrica *et al.* 1980; Kozur & Mostler 1981, 1982, 1994). They are well-known among the Cenozoic and Recent faunas (Hollande & Enjumet 1960; Friend & Riedel 1967). On the contrary, only few such taxa were illustrated and described from the Jurassic and Cretaceous (Dumitrica 1994; Yeh 1995). During the post-Triassic time some spicule-bearing Spumellaria survived with a low frequency. These large-sized Radiolaria can be recognized only in the case of good preservation of initial structures. Frequent spicule-bearing forms were found in the Upper Cretaceous radiolarian assemblages of the southern Sakhalin. These forms have morphological affinities with the Early-Middle Cretaceous genus *Pyloctostylus* Dumitrica, 1994 and may be descendants of this taxon. The genera *Pyloctostylus* Dumitrica and *Cuboctostylus* n. gen. have large eight-rayed spicule with long primary spines showing morphological affinity with the Paleozoic Entactinaria. Many Triassic spumellarians have small spicule without connections with primary spines (like genera *Pseudostylosphaera* Kozur & Mostler, 1981, *Sepsagon* Dumitrica, Kozur & Mostler, 1980) and cannot be ancestors of the Cretaceous taxa described herein.

GEOLOGICAL SETTING

The Upper Cretaceous key-section of the southern Sakhalin is located in the middle flow of Naiba River (Matsumoto 1938, 1954; Verecshagin *et al.* 1987) (Fig. 1). This section is represented by thin- and coarse-grained clastics with carbonate (calcilutite) concretions containing abundant ammonites, inoceramids and foraminifers. Several stratigraphic levels in the interval from the Albian to Campanian are characterized by bearing radiolarians (Kasinzova 1979, 1981; Verecshagin *et al.* 1987; Zonova *et al.* 1993).

The Cenomanian, Turonian and Coniacian deposits of the Naiba Section were studied and sampled by the author in 1992. Several radiolarian assemblages with spicule-bearing radiolarians were found. This part of section can be seen in outcrops at Shadrinka River and Naidenov Creek (west tributaries of Naiba River) (Fig. 1). The upper part of Cenomanian deposits is represented by the Naibinskaya Formation (Units 3, 4, 5) and Bykovskaya Formation (Units 1, 2). The Turonian is represented by the Bykovskaya Formation (Units 3, 4, 5 and the lower part of Unit 6), and the Coniacian is represented by the Bykovskaya Formation (upper part of Unit 6 and Unit 7).

NAIBA SECTION (Fig. 1)

Naibinskaya Formation (upper part)

Unit 3. Greenish-grey massive medium-grained sandstones with intercalations of grey siltstones. The thickness of this unit is 250-300 m.

Unit 4. (*Inoceramus tychljawajamensis* zone, lower Cenomanian-lower part of middle Cenomanian). Dark-grey massive mudstones and siltstones with small carbonate concretions with *Inoceramus tychljawajamensis* Vereschagin, 1967, *I. concentricus nipponicus* Nagao & Matsumoto, 1939, *Anagaudryceras buddha* (Forbes, 1846). The thickness of this unit is 300-450 m.

Unit 5. (*Inoceramus pennatulus-I. gradilis* zone, middle Cenomanian). Grey fine- to medium-grained sandstones and grey siltstones with rare carbonate concretions and beds of gravelites. This member is characterized by *Inoceramus pennatulus* Pergament, 1966, *I. gradilis* Pergament, 1966, *I. pressulus* Zonova, 1980. Radiolarians are represented by *Cromyomma* (?) *nodosa* Pessagno, 1976, *Hexapyramis pantanellii* Squinabol, 1903b, *Orbiculiforma maxima* Pessagno, 1976, *Amphipyndax stocki* (Campbell & Clark, 1944), *A. ellipticus* Nakaseko & Nishimura, 1981, *Dictyomitra multicostata* Zittel, 1876, *Cuboctostylus sakhalinensis* n. sp., *C. kasinzovae* n. sp. The thickness of this unit is 100-150 m.

Bykovskaya Formation (lower and middle parts)

Unit 1. (Upper Cenomanian). Alternation of light-grey fine-grained sandstones, dark-grey siltstones and black mudstones with abundant shell detritus of inoceramids and numerous car-

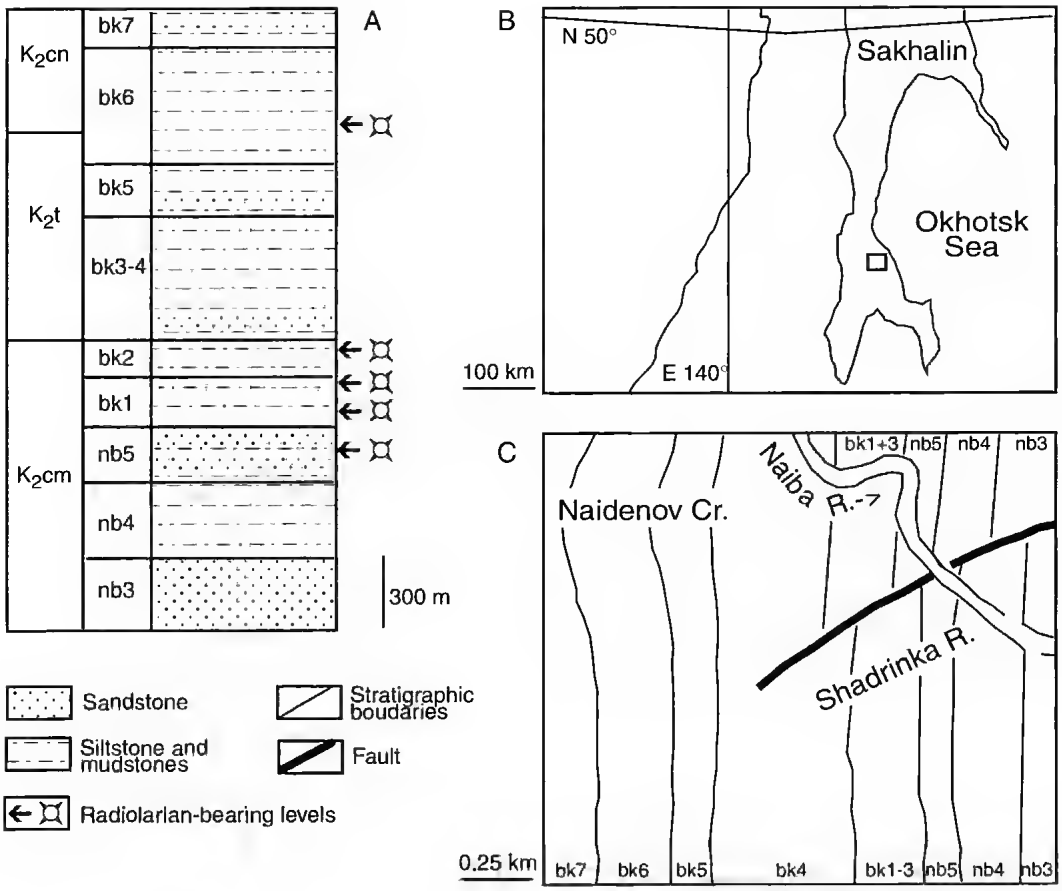

FIG. 1. — The Upper Cretaceous section at Naiba River (southern Sakhalin). **A**, stratigraphic column; **B**, geographic position; **C**, geological map of the middle flow of Naiba River; **K_2cm**, Cenomanian; **K_2t**, Turonian; **K_2cn**, Coniacian; **nb**, Naibinskaya Formation; **nb3**, third unit; **nb4**, fourth unit; **nb5**, fifth unit; **bk**, Bykovskaya Formation; **bk1**, first unit; **bk2**, second unit; **bk3**, third unit; **bk4**, fourth unit; **bk5**, fifth unit; **bk6**, sixth unit; **bk7**, seventh unit.

bonate concretions with *Inoceramus nipponicus* Nagao & Matsumoto, 1939, *I.* sp. aff. *I. tenuis* Mantell, 1822, *Gaudryceras varagurense* Kossmat, 1895 and radiolarians: *Cromyomma* (?) *nodosa* Pessagno, 1976, *Cyclastrum satoi* (Tumanda, 1989), *Dumitricaia maxwellensis* Pessagno, 1976, *Quadrigastrum insulsum* O'Dogherty, 1994, *Savaryella quadra* (Foreman, 1978a), *Phaseliforma* sp. ex gr. *P. laxa* Pessagno, 1972, *P. subcarinata* Pessagno, 1972, *Cornutella* sp., *Paronaella* sp., *Stylodruppa* sp., *Amphipyndax ellipticus* Nakaseko & Nishimura, 1981, *A. stocki* (Campbell & Clark, 1944), *Archaeodictyomitra squinaboli* Pessagno, 1976, *Cassideus yoloensis* Pessagno, 1969, *Neosciadiocapsa jenkinsi* Pessagno, 1975, *Saturniforma abastrum* Pessagno, 1970, *Cuboctostylus kasiuzovae* n. sp., *C. sakhalinensis* n. sp., *C. trifurcatus* n. sp. The thickness of this unit is 140-190 m.

Unit 2. (Upper Cenomanian). Dark-grey and grey siltstones with large carbonate concretions with *Inoceramus* sp. aff. *I. tenuis* Mantell and a radiolarian assemblage similar to that in Member 1. The thickness of this unit is 70-150 m.

Unit 3. (Lower Turonian). Alternation of greenish-grey medium-grained sandstones and dark-grey siltsrones with *Inoceramus* sp. aff. *I. tenuis* Mantell. The thickness of this unit is 60 m.

Unit 4. (Turonian). Dark-grey and black siltstones and mudstones with large carbonate concretions with *Mytiloides* sp. aff. *M. labiatus*

(Schlotheim, 1813). The thickness of this unit is 450 m.

Unit 5. (*Inoceramus hobetsensis* zone, middle part of Turonian). Grey siltstones with large carbonate concretions with *Nipponites mirabilis* Matsumoto, 1954, *Inoceramus hobetsensis* Nagao & Matsumoto, 1939. The thickness of this unit is 180-200 m.

Unit 6. (*Inoceramus teshioensis* zone, upper part of upper Turonian-lower Coniacian). Dark-grey siltstones and mudstones with carbonate concretions containing *Inoceramus teshioensis* Nagao & Matsumoto, 1939, *Gaudryceras denseplicatum* (Jimbo, 1894) and radiolarians: *Archaeospongoprunum cortinaensis* Pessagno, 1971b, *Crucella* sp. ex gr. *C. plana* Pessagno, 1971a, *Histiastrum* sp. ex gr. *H. aster* Lipman, 1952, *H. latum* Lipman, 1952, *Orbiculiforma monticelloensis* Pessagno, 1971b, *Patellula minuscula* O'Dogherty, 1994, *Patulibracchium* sp. aff. *P. arbucklensis* Pessagno, 1971a, *Phaseliforma* sp. ex gr. *P. carinata* Pessagno, 1972, *Spongotripus communis* Squinabol, 1903b, *Vitorfus brustolensis* (Squinabol, 1903b), *Multastrum* sp., *Afens liriodes* Riedel & Sanfilippo, 1974, *Dictyodedalus* sp. aff. *D. acuticephalus* (Squinabol, 1904), *Xitus* sp. ex gr. *X. antelopensis* Pessagno, 1977c, *X. spicularius* (Aliev, 1965), *Cuboctostylus kasinzovae* n. sp., *C. sakhalinensis* n. sp. The thickness of this unit is 500-600 m.

Unit 7. Dark-grey siltstones and mudstones. The thickness of this unit is 100-150 m.

SYSTEMATICS

Class RADIOLARIA Muller, 1858
Order POLYCYSTINA Ehrenberg, 1838
Suborder ENTACTINARIA
Kozur & Mostler, 1982
? Family POLYENTACTINIIDAE Nazarov, 1975

Genus *Cuboctostylus* n. gen.

TYPE SPECIES. — *Cuboctostylus kasinzovae* n. sp.

SPECIES INCLUDED. — *Cuboctostylus kasinzovae* n. sp., *C. sakhalinensis* n. sp., *C. trifurcatus* n. sp.

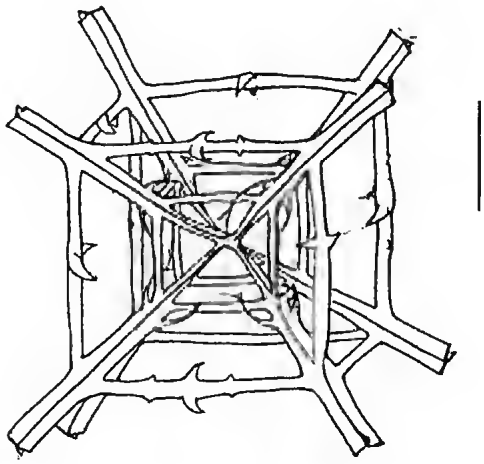

FIG. 2. — *Cuboctostylus kasinzovae* n. sp., suggested reconstruction. Scale bar: 200 µm.

ETYMOLOGY. — From the Greek *cubo* – cubic, *octo* – eight, *stylos* – spike, style.

OCCURENCE. — Cenomanian to Campanian so far as known.

DESCRIPTION

Skeleton large, with initial spicule in the center, and two or three concentric systems of cubic arches, the outermost with a subspherical latticed shell which may be missing. Spicule with a very short median bar and four spines at each end. Spines not differentiated into apical or basal. They result from successive bifurcation in horizontal and vertical planes. Spines cylindrical in the portion between MB and the innermost system of arches. They rapidly increase in width and become three-bladed outside cortical shell. Spines with two or three verticils of straight bars that unite the spines at two or three levels forming weakly developed cube-like shells. Spines aligned with the diagonal of the cube-like shells.

REMARKS

Cuboctostylus n. gen. differs from the Early to Middle Cretaceous genus *Pyloctostylus* Dumitrica by the central position of spicule and absence of pylome.

The genera *Pyloctostylus* Dumitrica and *Cuboctostylus* n. gen. undoubtedly belong to the same

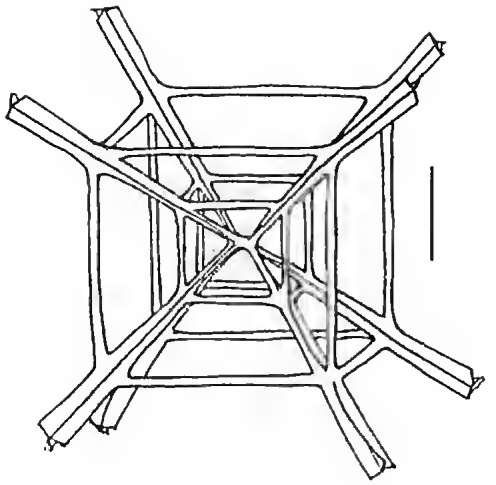

FIG. 3. — *Cuboctostylus sakhalinensis* n. sp., suggested reconstruction. Scale bar: 200 µm.

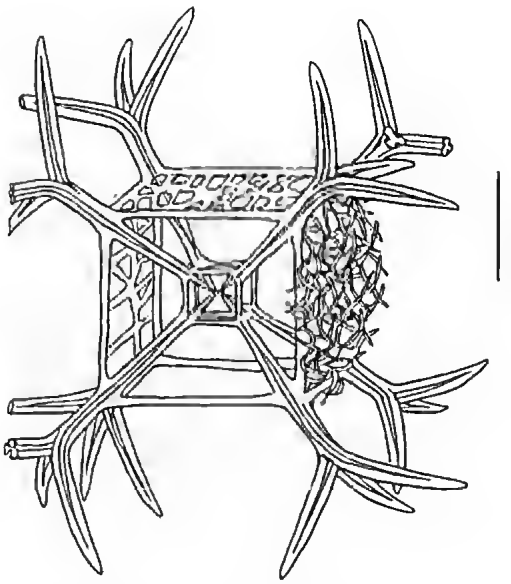

FIG. 4. — *Cuboctostylus trifurcatus* n. sp., suggested reconstruction. Scale bar: 200 µm.

phylogenetic lineage. Since *Cuboctostylus* n. gen. has no pylome it is morphologically closer to the Paleozoic genus *Polyentactinia* Foreman (Foreman 1963). Finding of this new genus shows that the spicule-bearing Spumellaria are much more frequent in the Cretaceous than was previously supposed. Dumitrica (1994) mentioned that there are many other spicule-bearing forms in the Cretaceous which are to be described.

Two Cretaceous spumellarian species – *Falsocromyodrymus ? fragosus* O'Dogherty, 1994 and *F. ? nebulosus* O'Dogherty, 1994 have some affinity with *Cuboctostylus* n. gen. (O'Dogherty 1994). Unfortunately, there is no evidence of their initial spicule and these taxa cannot be assigned now to the new genus.

Cuboctostylus kasinzovae n. sp.
(Figs 2, 5A-G, 6D, 7D-F, H)

HOLOTYPE. — GIN 4845-1, Fig. 5B, southern Sakhalin, Naiba River, Naibinskaya Formation, middle Cenomanian.

ETYMOLOGY. — The species is dedicated in honour of Ludmila I. Kasinzova, who discovered the Cretaceous Radiolaria of the Naiba sequence (south-western Sakhalin) and published their first descriptions.

OCCURRENCE. — Middle Cenomanian to Coniacian as far as known.

DIMENSIONS. — Length of the outer cube-like shell side 480-500 µm, length of the inner cube-like shell side 200-250 µm, total length of spine 900-1000 µm.

DESCRIPTION

Shell as with genus. Very short median bar with eight spines is placed in the central part of the shell. Robust outer shell and a single inner shell form two concentric cubes. Length of bars of the inner shell approximately half than of the outer shell. Spines cylindrical in the portion between MB and inner shell, beyond it three-bladed and increasing in thickness up to the outer shell. Each bar of the inner cube-like shell has one crescent-like apophyse at the corner. These apophyses form weakly developed secondary spherical level over inner shell. Each bar of the outer cube-like shell has two opposite apophyses in the middle and few short secondary spines.

REMARKS

This species differs from the species *C. trifurcatus* n. sp. by the absence of trifurcations of the distal

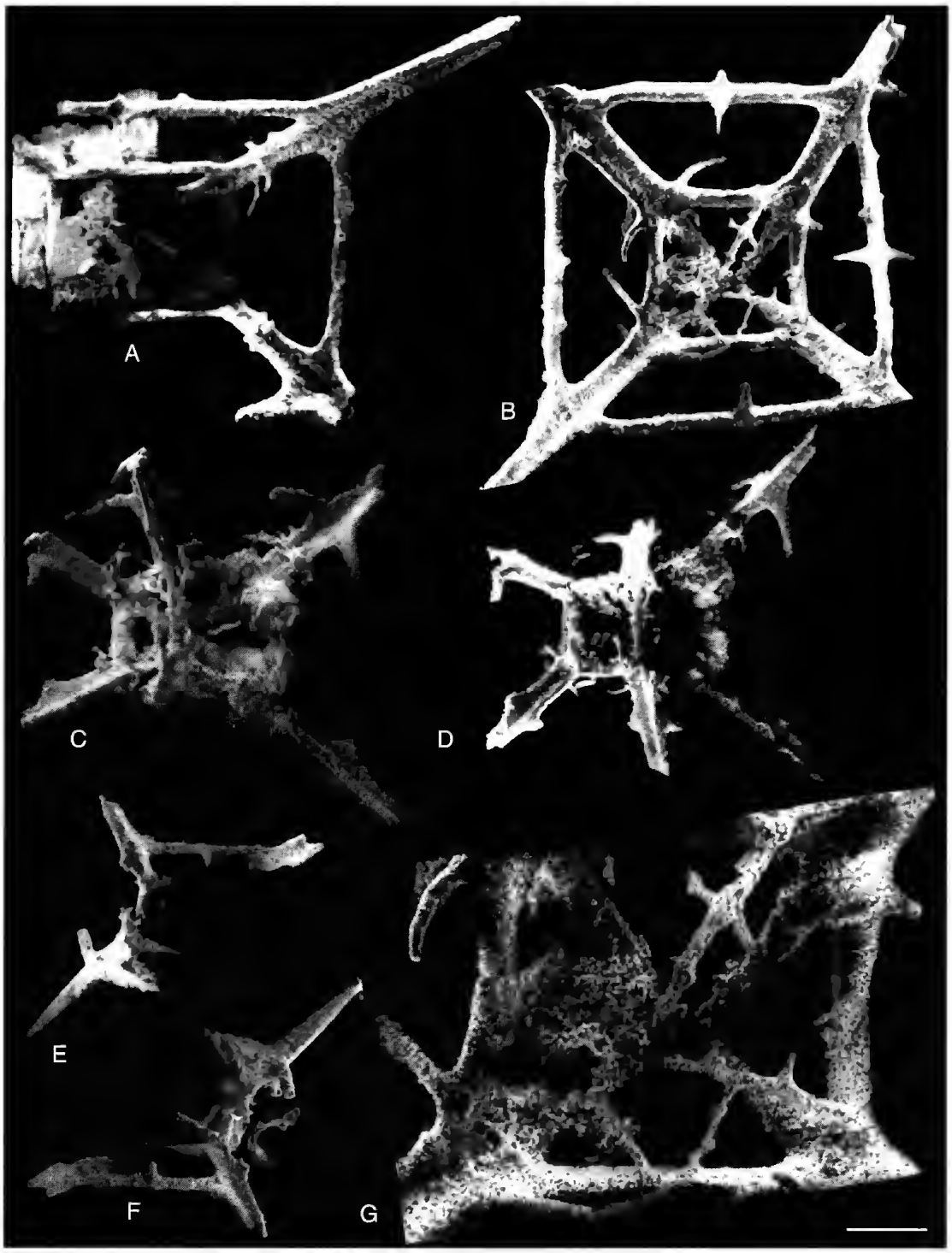

FIG. 5. — **A-G**, *Cuboctostylus kasinzovae* n. sp., **B**, holotype, GIN 4845-1; **C**, **D**, two foreshortening on internal part of shell; **E**, **F**, fragments of shell; **G**, part of B. Scale bar: A-D, 130 µm; E, F, 200 µm; C, 300 µm.

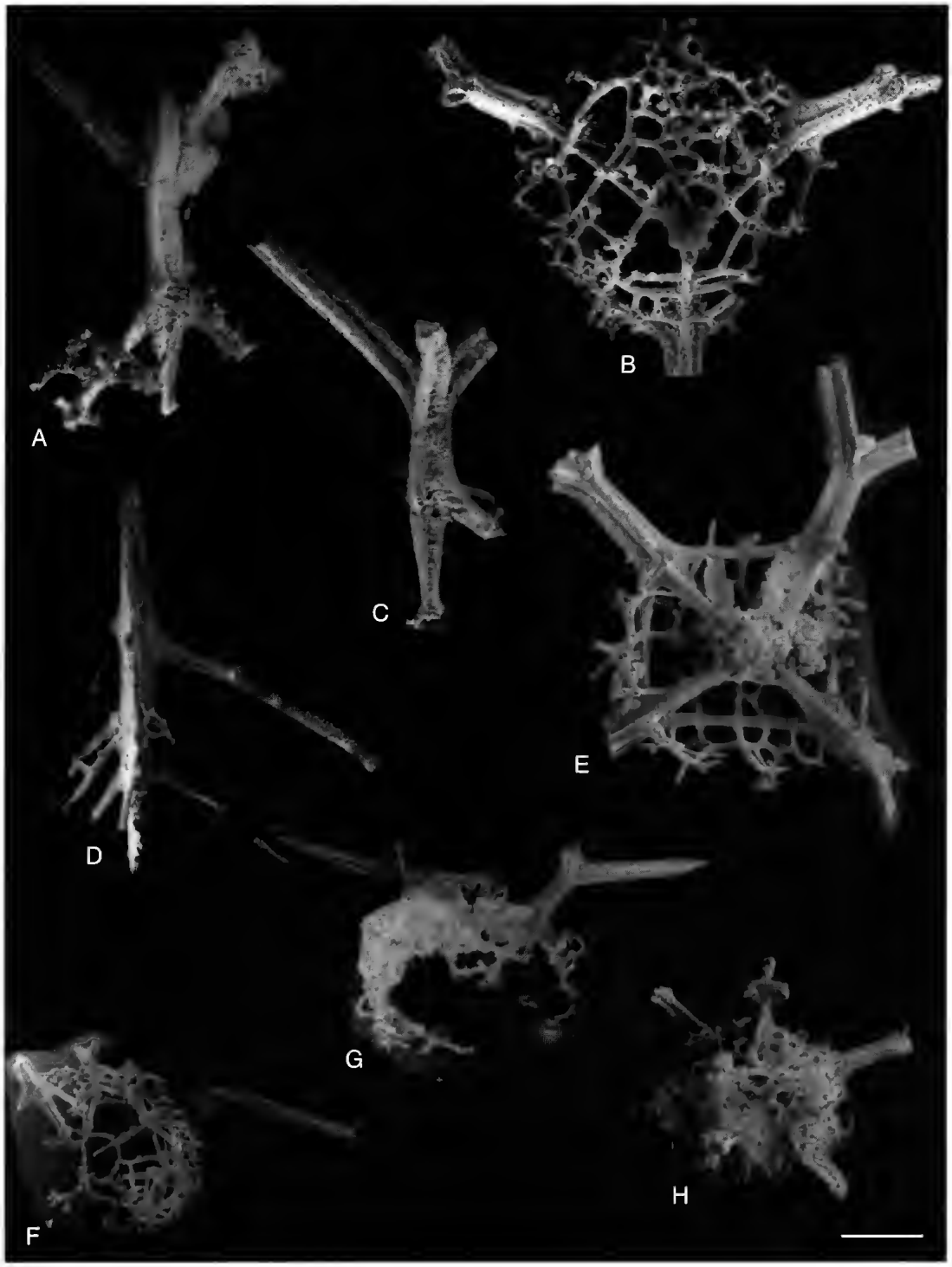

FIG. 6. — **A**, **C**, *Cuboctostylus trifurcatus* n. sp., spines; **B**, **E**, *Cuboctostylus trifurcatus* n. sp., holotype, GIN 4845-3; **B**, external view of shell; **E**, internal view of shell; both two fragments belong to one specimen; **D**, *Cuboctostylus kasinzovae* n. sp., main spine; **F**, **G**, *Cuboctostylus trifurcatus* n. sp., uncomplete shell; **H**, *Cuboctostylus trifurcatus* n. sp. Scale bar: A-E, 130 µm; F-H, 200 µm.

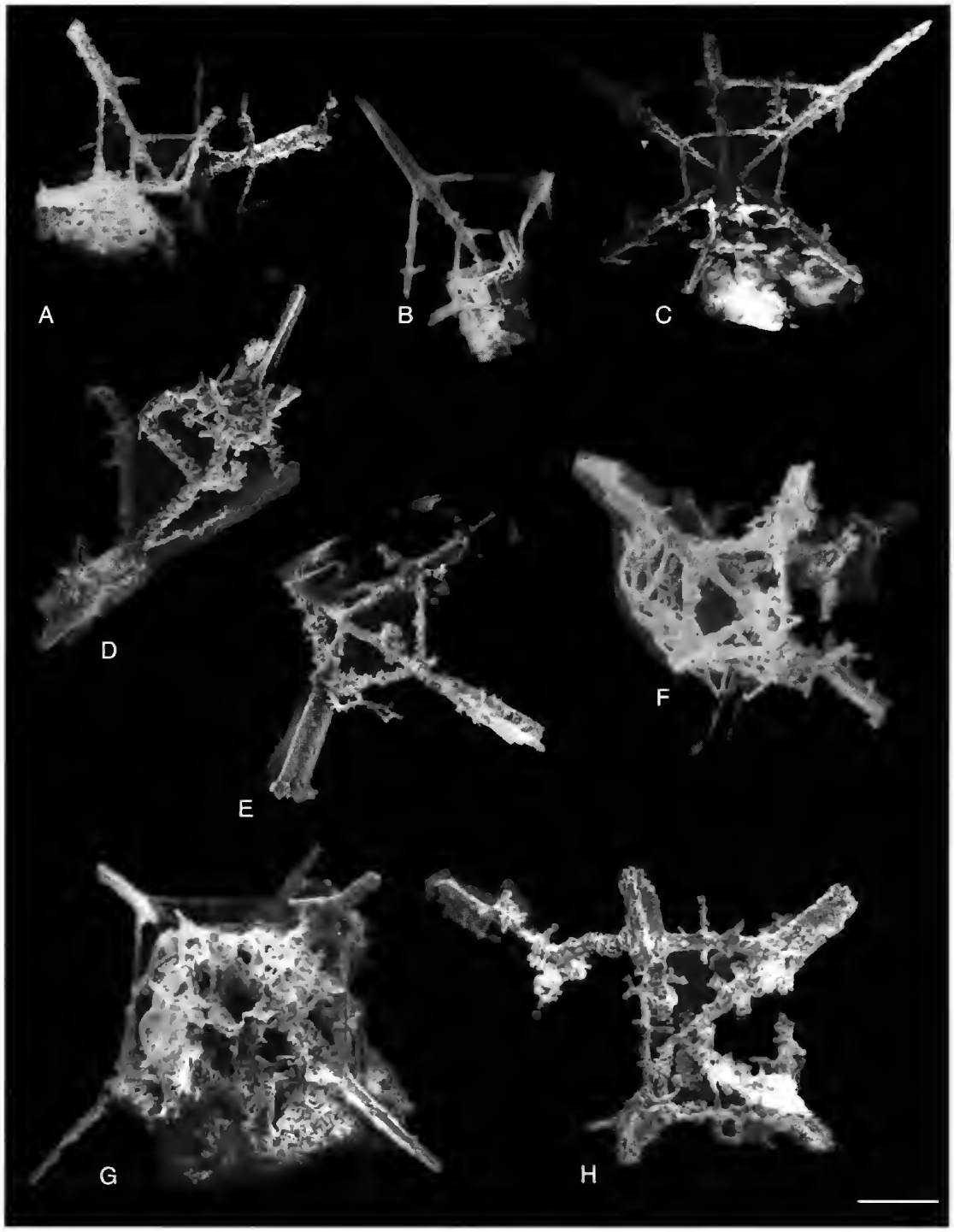

FIG. 7. — **A**, *Cuboctostylus sakhalinensis* n. sp., holotype, GIN 4845-2; **B**, **C**, *Cuboctostylus sakhalinensis* n. sp., uncomplete shell; **D**, **E**, *Cuboctostylus kasinzovae* n. sp., two fragments of one shell; **F**, *Cuboctostylus kasinzovae* n. sp., internal cube-like shell with developed apophyses; **G**, *Cuboctostylus sakhalinensis* n. sp.; **H**, *Cuboctostylus kasinzovae* n. sp., fragment of shell. Scale bar: A-C, G, 200 µm; D-F, H, 130 µm.

part of its main spines and from the species *C. sakhalinensis* n. sp. by the presence of apophyses at the outer and inner shells.

Cuboctostylus sakhalinensis n. sp.
(Figs 3, 7A-C, G)

HOLOTYPE. — GIN 4845-2, Fig. 7A, southern Sakhalin, Naiba River, Bykovskaya Formation, upper Cenomanian.

ETYMOLOGY. — From Sakhalin, eastern Russia.

OCCURRENCE. — Cenomanian to Campanian as far as known.

DIMENSIONS. — Length of the outer cube-like shell side 300-350 µm, length of the inner cube-like shell side 90-100 µm, total length of spines 600-800 µm.

DESCRIPTION
Large shell as with genus. Spines very long, simple. The outer and inner shells consist of the horizontal and vertical bars forming the edges of cube. Bars of the outer cube-like shell twice as long as those of the inner shell. Secondary spines or apophyses on these bars absent.

REMARKS
This species differs from *C. kasinzovae* n. sp. by having more delicate shells without secondary spines or apophyses. *C. sakhalinensis* n. sp. is characterized by a more exact geometrical form than the other representatives of *Cuboctostylus* n. gen.

Cuboctostylus trifurcatus n. sp.
(Figs 4, 6A-C, E-H)

HOLOTYPE. — GIN 4845-3, Fig. 6B, E, southern Sakhalin, Naiba River, Bykovskaya Formation, upper Cenomanian.

ETYMOLOGY. — From the Latin *tri* – three, *furcatus* – furcate.

OCCURRENCE. — Middle to upper Cenomanian so far as known.

DIMENSIONS. — Length of sides of the outer cube-like shell 300-350 µm, length of sides of the inner cube-like shell 80-100 µm, total length of spines 800-900 µm.

DESCRIPTION
Shell subspherical with eight very long trifurcate spines. Spicule with very short median bar is situated in the central part of the shell. Spines cylindrical in the position between MB and inner cube-like shell. They become three-bladed in the portion between inner and outer cube-like shells and rapidly increase in width. Outside the outer cube-like shell spines have a constant width. They have deep and narrow grooves and thick rounded ridges. Each spine divides into three terminations with same trefoil-like cross-section. Outer cube-like shell bars have numerous apophyses forming base of a latticed subspherical shell.

REMARKS
This species differs from *C. sakhalinensis* n. sp. and *C. kasinzovae* n. sp. by the trifurcation of spines, trefoil-like cross-section of the distal portions of main spines and by the presence of a latticed outer subspherical shell.

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I would like to thank P. De Wever who gave valuable recommendations in the early beginning of this work. The manuscript has been considerably improved by the critical reading of P. Dumitrica, E. Urquhart, and A. Ohler. This work was suppotted by the Russian Science Foundation (Grant 97-05-64646).

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A Middle Devonian radiolarian fauna from the Chotec Limestone (Eifelian) of the Prague Basin (Barrandian, Czech Republic)

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ABSTRACT
The occurrence of radiolarian faunas in the upper part of the Chotec Limestone is discussed in terms of faunal composition, systematics and geological implications. The most common entactinid species are treated systematically. The occurrence of radiolarians in large numbers in the rock succession began approximately 2 meters below the onset of the black shale sedimentation (Kacak Member). The abrupt sedimentological change, commonly viewed as an event therefore does not coincide with the faunal turnover, leading to a radiolarian dominance well before the onset of black shale deposition.

KEY WORDS
Radiolarians,
Middle Devonian,
upper Eifelian,
Barrandian,
Chotec Limestone,
Kacak event.

RÉSUMÉ
Une faune de radiolaires du Calcaire De Chotec (Devonien moyen, Eifelien supérieur) du bassin de Prague (Barrandien, République tchèque).
La présence de faunes de radiolaires dans la partie supérieure du Calcaire de Chotec est discutée en tenant compte de la composition faunique, de la systématique et des implications géologiques. Les espèces d'entactinés les plus communes sont traitées systématiquement. Les radiolaires sont présents en grand nombre dans la succession sédimentaire environ 2 mètres au-dessous des premiers schistes noirs (Kacak Formation). Le brusque changement de sédimentation ne correspond donc pas comme habituellement à un changement faunique, comme l'indique cette dominance des radiolaires bien avant le début de l'accumulation des schistes noirs.

MOTS CLÉS
Radiolaires,
Dévonien moyen,
Eifelien supérieur,
Barrandien,
Calcaire de Chotec,
Kacak Formation.

INTRODUCTION

The Paleozoic area around Prague is a famous and classical region for many investigations in paleontology and biostratigraphy. The occurrence of radiolatians in certain rocks especially of Silurian age has been commonly mentioned (Rodic 1925; Prantl 1949) and some very detailed petrographic studies have been carried out (Rodic 1931). Although typical radiolarian rocks (radiolarian cherts, lydites) are not very common especially in the Devonian sequence it has been known for some decades, that some lithologies may bear radiolarian skeletons in significant amounts (Fabian 1933). The fact, that some of the sedimentary tocks in the Barrandian area bear well preserved radiolarians, is not well known, although in cases where preservation is good such occurrences might be of special importance for our knowledge of stratigraphy and development of radiolarian faunas during the Silurian and Devonian. The fauna that is figured and partly described in this paper has been considered in two earlier papers (Cejchan 1987; Budil 1995). The present paper intends to supply some addional information, observations and a systematic treatment of the common entactinid species in these faunas. The special lithologic framework in which these faunas occur may be worth noting in the context of the "bioevent character" of the Kacak sequence (and the "otomari-event", cf.Walliser 1984), immediately overlying the source rocks of our faunas.

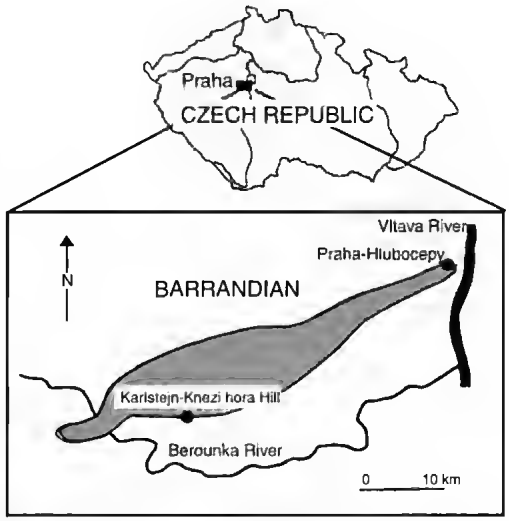

FIG. 1. — Distribution of the Kacak Member (in black) in the Barrandian area and geographic situation of the discussed localities.

LOCALITIES (cf. Figs 1, 2)

Radiolarian bearing rock samples come from two localities situated near Prague:

1. Railway cut in Praha 5-Hlupocepy. This exposure has been figured and described several times (e.g., in Budil 1995: 2-4; Chlupac 1960, 1993). It exposes a sucession from the higher part of the Chotec Limestone until the Roblin beds, overlying the Kacak Member. The Radiolarians have been extracted from a 15 cm thick bed of Chotec Limestone 50 cm below the base of the predominantly black siliceous Kacak sequence. Rare findings of radiolarian faunas come from rocks 4 m below the Kacak sequence (Budil 1995).

2. Knezi hora hill near Karlstejn. This locality, although offering a good sequence through the uppermost Chotec Limestone and the base of the Kacak Member in its typical development, had not been studied in detail until quite recently (Budil 1995: 4-8). Radiolarians are even better preserved here than those from the Hlupocepy railway cut. Our sample comes from two limestone beds approx. 2 m resp. 1 m below the Kacak base (beds -10/-12 and -20).

LITHOLOGY

The radiolarians come from the uppermost part of the Chotec Limestone (biomicritic limestones with intercalations of pelbiodetritic limestones) underlying the predominantly siliceous black sequence, the latter representing the so called Kacak event (Chlupac 1989). The limestone occurs in beds of thicknesses between 5 and 30 cm. It is dark grey in colour and bituminous. The cherts of the Kacak sequence, restricted to the area around Prague, have long been known to contain radiolarians (Fabian 1933; see

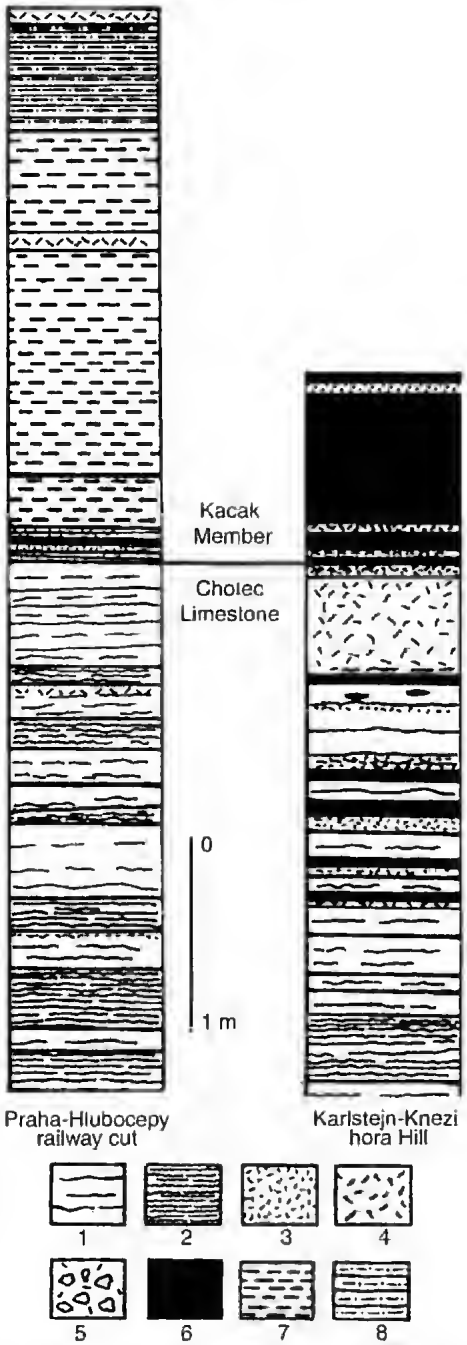

FIG. 2. — Lithologic succession of the sequences exposed at Praha-Hlubocepy railway cut and Karlstejn-Knezi hora hill. Note the different lithologic composition of the Kacak Member at the two localities. 1, massive biomicritic limestones; 2, thin bedded biomicritic limestones; 3, fine biodetrital limestones; 4, coarse biodetrital limestones; 5, lithoclastic breccia (not present in the sequence shown); 6, dark calcareous claystones and clay limestones; 7, thin bedded cherts; 8, calcareous siltstones and biodetritic limestones with silt.

Chlupac 1960: 176) for changes in terminology of the sequences). Radiolarian preservation seems to be more favorable in the limestone beds compared to the Kacak cherts.

AGE CONTROL

According to faunal data, the Kacak succession 2 m above the upper Chotec Limestone was initially considered to be basal Givetian (Chlupac 1960: 177), and later regarded uppermost Eifelian (Chlupac & Kukal 1986, 1988; Chlupac 1993). Kalvoda (1992) discussed the stratigraphic implications of conodonts in beds near the base of the Kacak sequence which in terms of the conodont chronology indicate an upper *Tortodus kockelianus* zone age (near the base of the *Polygnathus ensensis* zone). In terms of modern conodont chronologies (Sandberg & Ziegler 1996; Weddige 1996) this zone is well below the actual Eifelian/Givetian boundary. As our sample horizon is located a maximum of 2 m below the Kacak base our radiolarian fauna presumably also belongs to the upper *Tortodus kockelianus* zone. Budil (1995) discusses the considered interval (Chotec-Kacak boundary interval) in terms of the uppermost Eifelian. Because of the scarcity of well preserved conodonts and other faunas, the question of where the actual Eifelian/Givetian boundary is situated within the sequence has not been resolved. It is clear however, that on the basis of recent conodont zonation schemes (Sandberg & Ziegler 1996) the radiolarian faunas discussed herein stratigraphically belong to the upper Eifelian.

TECHNIQUES OF STUDY

The limestone samples were acid treated as in any processing for conodonts, in this case with acetic acid. Isolated radiolarians from the residue have been either picked and mounted on SEM stubs or embedded in Caedax for light microscopy. The latter technique serves well in the investigation of internal structures, which are of importance in generic and suprageneric taxonomy of spherical radiolarians.

SYSTEMATIC PALEONTOLOGY

The radiolarian fauna in general is dominated by Entactiniidae in terms of absolute numbers and species diversity. Ceratoikiscids and Palaeosceniids are rarer. All radiolarians are exceptionally well-preserved; in many of the entactinids the internal structures are present. Whereas in the Ceratoikiscids several clearly different morphotypes are distinguishable, the genus *Palaeoscenidium* is present only with one species. As the ceratoikiscids and palaeoscenids have been systematically treated in the paper of Cejchan (1987) no detailed taxonomic discussions of these will be made here. A more detailed taxonomic treatment is given for the most common species of entactinids.
Material figured and mentioned in the text (SEM stubs, light microscope slides) are housed at the collection of the Institute of Paleontology, University of Bonn. Coordinates given for specimens on numbered slides refer to the cross stage of a "Biolam M" microscope belonging to A. Braun.

Order ALBAILLELLARIA Deflandre, 1953
Family CERATOIKISCIDAE Holdsworth, 1969

Genus *Ceratoikiscum* Deflandre, 1953
emend. Holdsworth, 1969
(Fig. 3G, H)

Species of *Ceratoikiscum* are present in a remarkably good state of preservation. At least seven different species are present, but presently no further important additions can be made to the descriptions and figures in Cejachan (1987). As in other systems (Silurian, Lower Carboniferous) Ceratoikiscids are potentially useful for biostratigraphic zonations in the Lower and Middle Devonian. The Ceratoikiscids in this fauna show strong similarities to the species described in Foreman (1963) from the North American Famennian.

Order ? SPUMELLARIDA Ehrenberg, 1875

Family ENTACTINIIDAE Riedel, 1967

Members of the Entactiniidae are the most common faunal constituents in the investigated faunas.

Genus *Stigmosphaerostylus* Rüst, 1892

For synonymy with *Entactinia* Foreman, 1963 and remarks see Aitchison & Stratford 1997.

TYPE SPECIES — *Stigmosphaerostylus notabilis* Rüst, 1982.

Stigmosphaerostylus herculeus (Foreman, 1963)
(Fig. 4B)

DESCRIPTION
Spherical skeleton bearing six three-bladed spines, the length of which is approximately equal to the diameter of the skeletal sphere. Spines may be disposed at 90° angles to one another or placed slightly asymmetrical. No secondary spines have been observed, only small thornlike elevations are present at the corners of the lattice. About ten faily large, subcircular pores are present per half circumference. The specimen in slide K.h. -20 AC/3, r: 22, h: 13,5 shows a bar centered internal spicule, the spicular rays display a trifurcation before they reach the base of the spines. The specimen in slide K.h. -20/1, r: 22, h: 19 shows an excentric double spicule.

REMARKS
The specimens from our samples closely correspond in morphology to the paratype of *S. herculea* (Foreman, 1963) in Foreman (1963; pl. 1, figs 3C, D). Generic determination is based on characteristics of the internal structures of the skeleton.

Stigmosphaerostylus sp.
aff. ***S. herculeaus*** (Foreman, 1963)
(Fig. 4C, E, H)

aff. *Entactinia herculea* Foreman, 1963: pl. 1, fig. 3A-D (specimen in pl. 1, fig. 3B)

DESCRIPTION
Spherical skeleton with small, subangular pores (15 to 20 per half circumference) and six three-

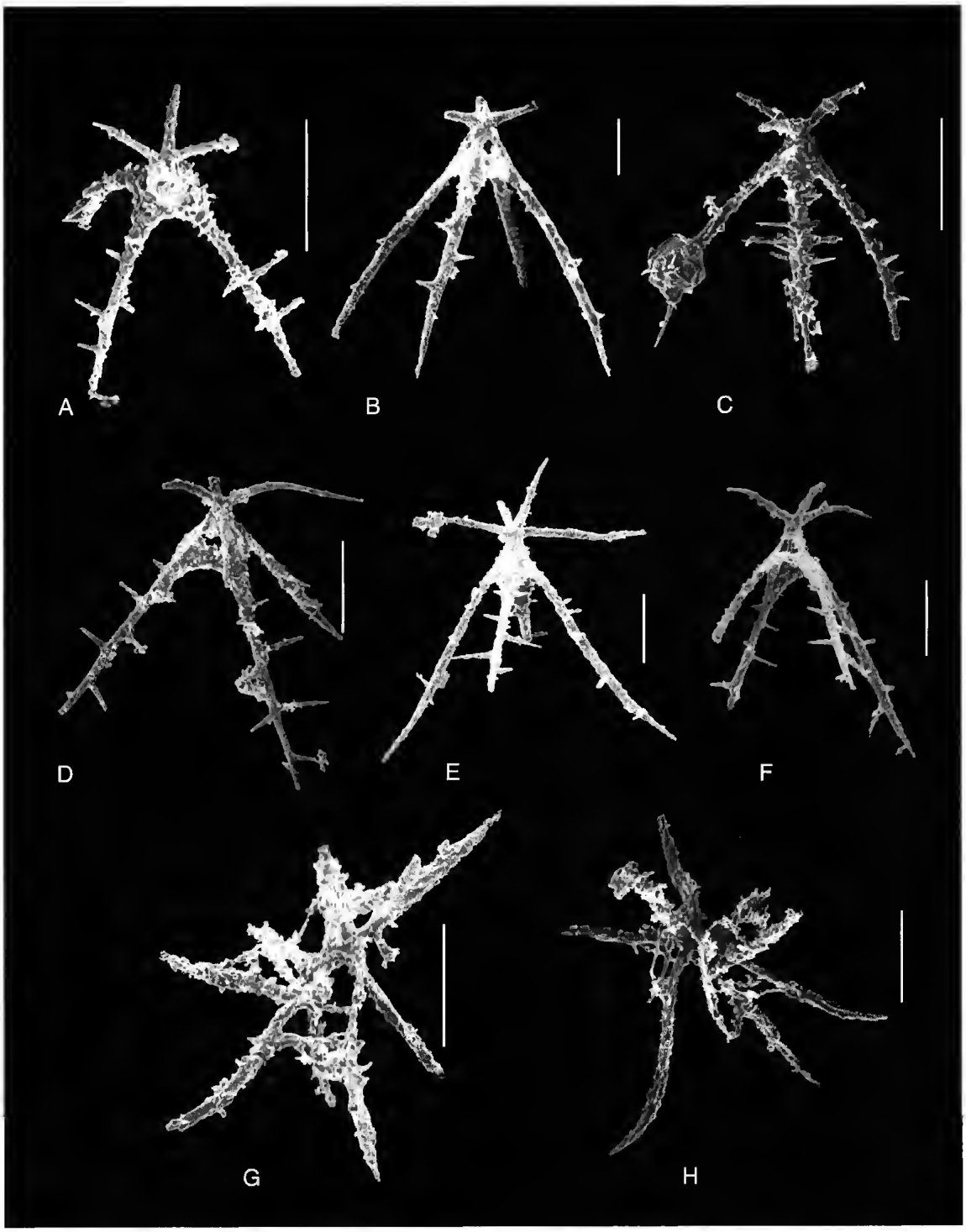

FIG. 3. — SEM micrographs of radiolarians from the Upper part of the Chotec Limestone (upper Eifelian). Knezi hora hill near Karlstejn. Palaeoscenidae and Ceratoikiscidae. **A-F**, *Palaeoscenidium cladophorum* Deflandre, 1953. Specimens displaying different sizes and numbers of basal spinules. **G**, **H**, *Ceratoikiscum* sp. Scale bars: 100 µm.

bladed spines disposed approximately at right angles to one another. The length of the spines varies from one to one time and a half the diameter of the skeletal sphere. Small thorn-like by-spines are present on the edges of the skeletal framework.

REMARKS

This taxon summarizes the entactinid morphotypes characterized by a spine morphology similar to *S. herculeus* (Foreman, 1963) but uniformly having smaller and more numerous pores. The character of pore size and number was observed here to be not highly variable and transitional between morphotypes, whereas length and width of spines was found to be much more variable. We therefore do not include the species with small pores into *S. herculea* as has been done by Foreman (1963), but place it in a different, presumably closely related species.

Stigmosphaerostylus sp.
aff. ***proceraspinus*** (Aitchison, 1993)
(Fig. 4I)

DESCRIPTION

Spherical skeleton possessing a lattice-shell and six three-bladed spines, one of which is considerably longer than the others. The longer spine is slightly twisted along its axis. Lattice with rounded pores of irregular size (about 10 per half circumference). The specimen in slide Kh -20/1, r: 20.5, h: 26.5 displays a well preserved internal double spicule, the center of which is placed excentrically towards the large spine.

COMPARISON AND REMARKS

Generic assignment is based on characteristics of the internal skeleton. There are several externally very similar species characterized by an internal sphere and therefore referred to *Trilonche* Hinde, 1899 (ex *Entactinosphaera* Foreman, 1963) in the literature. In pore size and general shape our material is similar to some specimens of *S. proceraspinus* (Aitchison 1993: 113, pl. 6, fig. 1). Other specimens referred to the same taxon in Aitchison (1993, pl. 7, fig. 1) have much longer and more equally sized spines and are presumably not conspecific with our material. Considering the smaller pores in the lattice sphere of the type of *E. proceraspina* Aitchison, 1993, we leave the specific designation open, but place our material in close connection to *S. proceraspinus*.

Stigmosphaerostylus? sp.
aff. ***S. hystricuosus*** (Aitchison, 1993)
(Fig. 4F, G)

DESCRIPTION

Small spherical skeleton possessing six long three-bladed spines. The length of the spines is more than three times the diameter of the skeletal sphere.

Each spine bears a set of three spinules at one half of their length, each spinule being placed on one of the spine blades. A few specimens in light microscope slides possess remnants of more spinules (slide K.h. -20/2, r: 23.5, h: 26) which are not always disposed at the same level of the spines (slide K.h. -20 AC/3, r: 20.5, h: 17). The specimen in slide K.h. -20 AC/1, r: 26, h: 22 shows a distal bifurcation in some of the spinules. The skeletal lattice possesses fairly large, polygonal pores of irregular size (four to six per half circumference).

COMPARISON AND REMARKS

Aitchison (1993) described several entactinid species possessing main spines with spinules from the Frasnian of Western Australia. Only in *S. hystricuosus* (Aitchison, 1993) however the size relations of the central shell and spines are comparable with our Bohemian material. In contrast to the type material of *S. hystricuosus*, only a few of our specimens possess more than a single tier of spinules on their main spines whereas *S. hystricuosus* is regularly characterized by several tiers of spinules. Concerning the externally similar material described as *Entactinia additiva* ? Foreman, 1963 by Nazarov *et al.* (1982), we refer to the remarks in Aitchison (1993: 113).

Genus *Trilonche* Hinde, 1899 *emend.* Foreman, 1963; Aitchison & Stratford, 1997

For synonymy with *Entactinosphaera* Foreman 1963 and further taxonomic discussions see Aitchison & Stratford (1997: 373).

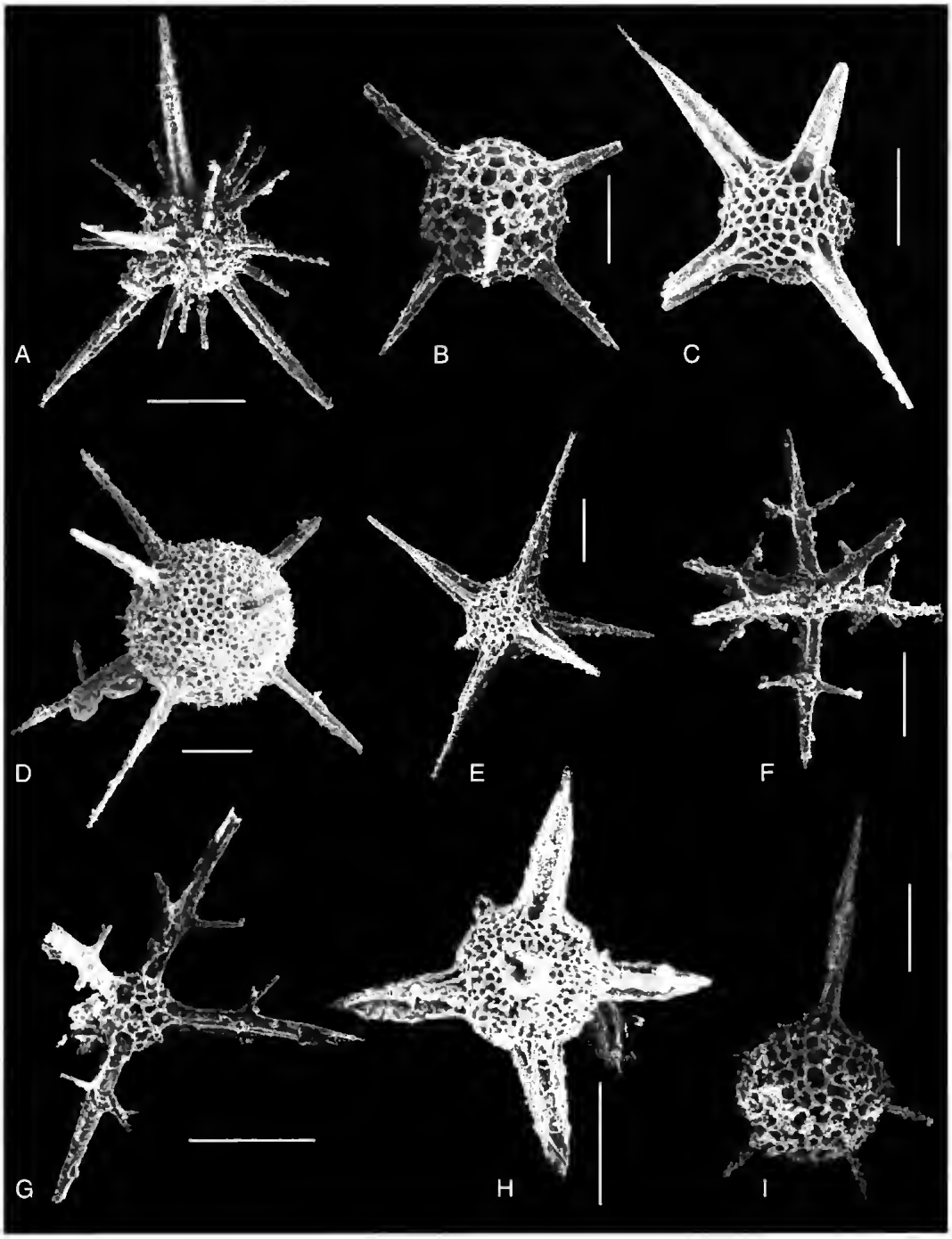

FIG. 4. — SEM micrographs of radiolarians from the Upper part of the Chotec Limestone (upper Eifelian). Knezi hora hill near Karlstejn. **A**, *Trilonche* ? *echinata* (Hinde, 1899) *sensu* Foreman, 1963; **B**, *Stigmosphaerostylus herculeus* (Foreman, 1963); **C**, **E**, **H**, *Stigmosphaerostylus* sp. aff. *S. herculeus* (Foreman, 1963); **D**, *Trilonche* sp. aff. *T. riedeli* (Foreman, 1963); **F**, **G**, *Stigmosphaerostylus* ? sp. aff. *S. hystricuosus* (Aitchison, 1993); **I**, *Stigmosphaerostylus* sp. aff. *S. proceraspinus* (Aitchison, 1993). Scale bars: 100 µm.

TYPE SPECIES. — *Trilonche vetusta* Hinde, 1899.

Trilonche sp.
aff. ***T. riedeli*** (Foreman, 1963)
(Fig. 4D)

DESCRIPTION
Fairly large spherical skeleton possessing eight narrow three-bladed main spines and numerous small pores. The spines are narrow and only indistinctly three-bladed. Small acute thorn like by-spines are arising from the edges of the lattice sometimes giving rise to a delicate meshwork partly covering the pore bearing skeletal lattice. Light microscope slides (K. h. -20/1, r: 24, h: 21) show an internal sphere.

REMARKS
The specific designation has been done on the basis of the characteristic spine morphology as well as on the basis of the overall morphology of the spherical skeleton. Pore size however in the type material in Foreman (1963, pl. 5, fig. 4 A-C) is larger and the number of spines in Foreman's material is smaller (only six compared to eight in our material). The specimen from the Frasnian of Western Australia figured as ?*Spongentactinella* sp. 1 GSWA F44073 in Aitchison (1993, pl. 7, fig. 5) is externally very similar to our material.

Trilonche ? echinata (Hinde, 1899)
sensu Foreman 1963
(Fig. 4A)

DESCRIPTION
Medium sized spherical latticed skeleton possessing six three-bladed main spines besides long rod-like by-spines. The length of the main spines is exceeding the diameter of the central skeleton, the length of the by-spines approximately equals the skeletal diameter. Lattice shell with small, regularly sized, angular pores (about 20 per half circumference).

REMARKS
The species designation is based on the morphology of the spines in the sense used by Foreman (1963). Generic assignment remains questionable as no internal structures could be found. The spine morphology in this taxon has in our material been found to be a constant character without great variability and transitions to other species. Similar material has been figured and described as *Entactinosphaera echinata* (Hinde) (now *T. echinata* by synonymy) by Aitchison (1993: 115, pl. 5, figs 6, 11, 14, pl. 7, fig. 3) from the Frasnian of Western Australia.

Order *Incertae Sedis*
Family PALAEOSCENIIDAE Riedel, 1967
emend. Goodbody, 1986
Genus *Palaeoscenidium* Deflandre, 1953

Palaeoscenidium cladophorum Deflandre, 1953
(Fig. 3A-F)

REMARKS
The figures show the skeleton of *P. cladophorum* in various orientations. Four distinct apical spines are present. The development of spinules on the basal spines is variable both in size and density. *P. cladophorum* is also common in Frasnian (Aitchison 1993), Famennian (Foreman 1963; Schmidt-Effing 1988; Kiessling & Tragelehn 1994) and Lower Carboniferous (Braun 1990) radiolarian faunas (up to the *Albaillella deflandrei* zone of the radiolarian zonation in Braun & Schmidt-Effing (1993).

RELEVANCE OF THE FAUNA IN THE EVOLUTIONARY CONTEXT

Radiolarians from the Upper Silurian and the Upper Devonian are different in various aspects. One of the main differences is the suprageneric composition of the spherical radiolarians, which belong to the Entactiniidae in the Upper Devonian (and are predominant at least in the Upper Paleozoic) and to other distinctly different groups in the Silurian (Inaniguttidae Nazarov & Ormiston, 1984, Rotasphaeracea Noble, 1994 and other groups not yet taxonomically separated). Looking at spherical radiolarians only, the impression arises, that there was a kind of "major turnover" somewhere during the Early or Middle

Devonian, leading to the disappearance of the Silurian Sphaerellaria and the predominance of the Entactinids. Based on these observations postulations of a sharp faunal change during Early or Middle Devonian have been made (Nazarov & Ormiston 1986). Recent findings of well-preserved radiolarian faunas from this interval indicate however that this trend was more gradual than originally assumed (Furutani 1983; Kiessling & Tragelehn 1994). Descriptions of well-preserved faunas are of great importance for any further consideration of this time interval in radiolarian evolution. In terms of this question, the spherical radiolarians of the upper Eifelian fauna presently treated are "completely" modern with respect to Upper Devonian and Carboniferous to Permian faunas. There are no remnants of groups of higher taxonomic level characteristic for the Silurian as far as our investigations have proceeded. Thus, the major Silurian groups must have disappeared before the Late Eifelian and by that time the Entactinids must have gained their numeral predominance and modernity of their morphologic characters. This evolution probably took place during the Early Devonian, still devoid of any radiolarian fauna well enough preserved to make substanciated statements on the taxonomic constitution. Probably, future investigations will be successful in finding well preserved faunas in uppermost Silurian and Lower Devonian strata in the Barrandian area. The presence of uppermost Silurian (Pridolian) radiolarians in limestones of this area has been proven [Literature data and material donated by Dr. H. Jaeger, Berlin (†)], but other well preserved material needs to be found for further work and other lithologies in the Lower Devonian need to be investigated.

It is worth noting, that the seemingly sharp difference between Upper Silurian and Upper Devonian radiolarians exists only in the spherical radiolarians. According to the material collected up to now, Ceratoikiscids develop at a fairly constant rate from their first known occurrence in the Wenlockian, and the spicular Palaeosceniidae are seemingly only going through a decline because this group is present in Upper Silurian faunas with considerably greater taxonomic variety (Goodbody 1986; Amon *et al.* 1994).

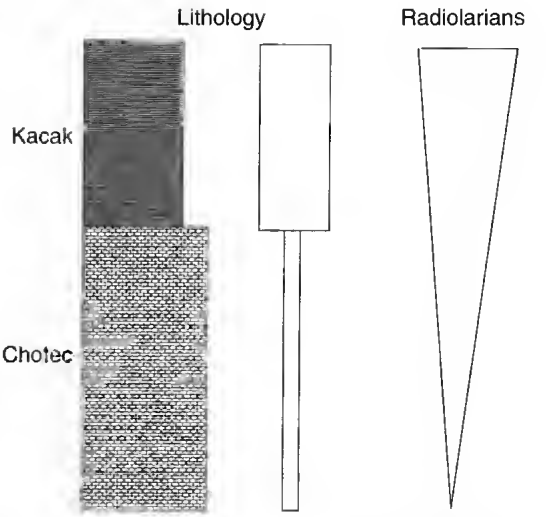

FIG. 5. — Schematic representation of the observed differences between lithologic and faunal change near the Chotec Limestone-Kacak Member boundary.

GEOLOGIC SIGNIFICANCE (A. Braun)

Conspicuous change in sedimentary composition between the Chotec Limestone and the Kacak sequence is a feature similar to that of many sedimentary units assinged to this time interval in other areas (Weddige 1986: 281) and may indicate some form of transgressive changes (see House 1984; Haas 1994; Walliser 1994, 1995). Observations of the colours and composition of sediments attributed to this stratigraphic interval indicate that a transgressive deepening event is the most likely explanation for the observed geological phenomena (Walliser 1995, fig. 3). Transgression may have lead to reduction in sediment supply by drowning source areas of clastic sediments. Planctonic organisms penecontemporaneously began to dominate the communities because of the changes in water depth (and probably circulation). This may finally have resulted in the formation of "biosiliceous" deposits within condensed sediments, such as the cherts of the Kacak Member which developed in the area around Prague.

Furthermore the above mentioned change in sedimentary composition is interpreted in terms of a short termed, abrupt event ("Kacak event";

Chlupac 1989: 483). The abrupt change in sedimentological composition from the Chotec Limestone to the Kacak chert sequence seems to imply a similarly abrupt change in environmental factors and it is general opinion, that most "bio-events" coincide with lithological changes ("most of the global bio-events are connected with a litho-event, i. e. a strong facies change"; Walliser 1995: 4). Looking at the predominant lithology it may seem to be obvious in our example to assume a sudden bloom of radiolarians following a "normal" Chotec Limestone organism assemblage (trilobites, tentaculites, conodonts etc.) which led to a similarly sharp lithological boundary between limestone and radiolarian-dominated cherts in sections near Prague (Hlupocepy railway cut, Barrandov), and to some extent in other sections as well.

The Barrandian localities treated in this paper may, because of their particular sedimentary facies contribute to this discussion because the sediments present here (limestones) allow for a good preservation of the organisms under consideration (calcareous hard parts as well as radiolarian skeletons).

The following observations can be made:

The abrupt change in sediment type is, in terms of paleoecology, not paralleled by an abrupt change in fossil content. Predominance and preservation of Radiolaria began at least as early as deposition of the uppermost 2 m unit of the Chotec Limestones. In the uppermost part of the Chotec Limestone, typical "Chotec-Limestone"-organisms become rarer and less well-preserved as mentioned by several authors. Some last remains of the typical "Chotec Limestone fauna" however have been described from the last few decimetres of the Chotec limestone formation (Budil 1995). Only after such a general shift in organism population did the abrupt change in sedimentological realm occur.

There were biological changes within the considered interval of uppermost Chotec limestones and lower Kacak Member. In biological terms however, gradual "extinctions" and entrances in organism ecology occur well before the clearly visible changes in sediment facies and can be observed over at least 2 m of sediment thickness. Disregarding the highly hypothetical question as to how much time may be represented by these 2 meters, it is obvious in non-turbiditic sediments of sedimentary basins like the Barrandian, that the time interval neccessary for their deposition cannot be called an abrupt event in terms of days, months or even a few years

Higher up in the sequence (at the Kacak base) such ecological shifts were paralleled by changes in the predominant composition of the sediments, and it is quite probable, that such compositional changes were in our case also later diagenetically enhanced to give the sharp contrast as seen in todays outcrops.

Thus, the Kacak event, being presumably due to changes in water depth and sediment supply leaving traces in many other areas, can be shown to have occurred ecologically more gradually than implied when only considering the sedimentological boundaries. These observations exclude catastrophic pictures arising when reading the terminology sometimes used in event discussions, and contribute to the picture of many of such events as "mild" ones in the terminology of Walliser (1995).

It is not our aim to cast doubt on the general existence of relatively short-termed processes known to be present during the Phanerozoic (Walliser 1995), that changed sedimentological characters as well as the living conditions of organisms and causing ecological stresses as a possible reason for larger scale extinctions, organism displacements etc.. And in view of the published considerations on possible causes and natures of "events" (Walliser 1995), it would surely be not justified to restrict our view of events to asteroid impacts and to discuss any proposed event (sedimentologically or organism-based) in the light of such extraterrestrial causes, which are the exception rather than the rule (Walliser 1995). Thus, we do not reject the existence of the Kacak "events" as long as the use of the term event does not imply a short term catastrophical happening. Many such processes as far as we know today seem to be closely connected to changes in sea level (Johnson *et al.* 1985; Ross & Ross 1985; Walliser 1995), whatever their causes might have been, and it is clear, that such changes could well have lasted even a few million years. At least in some cases however such changes do not coinci-

de with lithological boundaries. This, based on the present observations, can be shown to be true in the case of the Kacak event. The latter as far as it is represented by the typical (cherty) sediments was only the culmination of a transgressive deepening, leaving its faunal traces well before the actual Kacak sequence.

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Radiolarians from the cyclic Messinian diatomites of Falconara (Sicily, Italy)

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ABSTRACT

The diatomitic sediments in Falconara (6.93 to 6.08 Ma) have a total thickness of *c.* 27 m, and the sequence is composed of 41 diatomite/claystone couplets. The deposition of these biosiliceous sediments, seemingly modulated by the astronomical precession cycle (21,000 years period), has been suggested to have taken place in a shallow basin with diatomaceous and claystone sediments being deposited during low and high sea level stands, respectively. Polycystine radiolarians show major changes in the assemblage compositions and the total abundances between the different cycles, from being barren in Cycle 2 till > 142,000 radiolarians/g in Cycle 26. Radiolarians are usually not present in the claystone samples, this is also the case with diatoms. However, one claystone (S11) had a significant high number, > 43,000 radiolarians/g sediment, while nine others had a low content of radiolarians. We have in our counts recognised 68 morphotypes. Q-Mode Factor analysis has been used on the raw counting data. By using five factors, we were able to explain 83.65% of the cumulative variance, while using nine factors allowed us to explain 96.52% of the variance. These nine factors displayed well-defined peaks that can be used to navigate within the profile and to correlate between sections. Another high resolution stratigraphical tool could be reptesented by the peculiar faunal composition of each of the diatomites. In our pilot study we selected three diatomites and

KEY WORDS
Radiolaria,
Miocene,
Italy,
ciclicity.

compared their assemblage composition and radiolatian abundances. Cycle 11 is dominated by *Stichocorys delmontensis* and *Lithomitra lineata*, *c.* 50 and 36% maximum values respectively. In Cycle 21, *S. delmontensis* and *Botryostrobus auritus/australis* are most common, with 40 and 30% as maximum values respectively. In both these cycles nassellarians are the dominant group. In Cycle 26 Larcoidea sp., *Porodiscus* sp., and *Spongotrochus glacialis* are the dominant taxa.

RÉSUMÉ

Radiolaires des sédiments messiniens à diatomées de Falconara (Sicile, Italie).

Les sédiments à diatomées de Falconara (agés de 6,93 à 6,08 millions d'années) ont une épaisseur totale d'environ 27 m. La séquence est composée de 41 paires diatomite/argile. Le dépôt de ces sédiments biosiliceux est apparemment modulé par le cycle de précession astronomique (avec une période de 21000 ans) et semble avoir eu lieu dans un bassin peu profond; les sédiments à diatomées et argileux correspondent respectivement à des périodes de bas et haut niveau marin. La composition des assemblages à radiolaires polycystines et l'abondance de ceux-ci varient beaucoup d'un cycle à l'autre, d'absent dans le cycle 2 jusqu'à plus de 142000 radiolaires/g dans le cycle 26. Les radiolaires, ainsi que les diatomées, sont généralement absents des échantillons argileux. Cependant, une argile (S11) a une concentration élevée (> 43000 radiolaires/g) et neuf autres ont une faible concentration. Nous avons compté 68 morphotypes. Les données brutes ont été soumises à une analyse factorielle en mode Q. Avec cinq facteurs, nous pouvons expliquer 83,65 % de la variance cumulée, tandis que neuf facteurs sont nécessaires pour rendre compte de 96,52 % de cette variance. Ces neufs facteurs montrent des maximums bien définis qui peuvent être utilisés pour naviguer le long du profil et pour corréler les différentes coupes. Une autre méthode permettant une bonne résolution stratigraphique pourrait être fondée sur la faune particulière à chacune de ces diatomites. Dans une étude pilote, nous avons choisi trois diatomites et nous avons comparé la composition de leurs assemblages et leur abondance en radiolaires. Le cycle 11 est dominé par *Stichocorys delmontensis* et *Lithomitra lineata*, avec des maximum à environ 50 % et 36 % respectivement. Dans le cycle 21, *S. delmontensis* et *Botryostrobus auritus/australis* sont les plus communs, avec des maximum à environ 40 % et 30 % respectivement. Pour ces deux cycles, les nassellaires forment le groupe dominant. Dans le cycle 26, Larcoidea sp., *Porodiscus* sp., et *Spongotrochus glacialis* sont les taxons dominants.

MOTS CLÉS
Radiolaires,
Miocène,
Italie,
périodicité.

INTRODUCTION

The biogenic siliceous sediments of Sicily have been known for almost 125 years. Ehrenberg (1854) and Mottura (1871) reported on radiolarians from the Sicilian Neogene, while Sauvage (1873) described, in fairly good detail, foliated, radiolarian bearing shale outcrops near Licata (Fig. 1). He assigned a Messinian-Zanclean age to them. Stöhr (1876, 1878) and Schwager (1878) studied Tortonian and Zanclean diatomites and tuffs containing rich radiolarian assemblages. Nicotra (1882) examined Tortonian diatomites containing radiolarians near Messina.

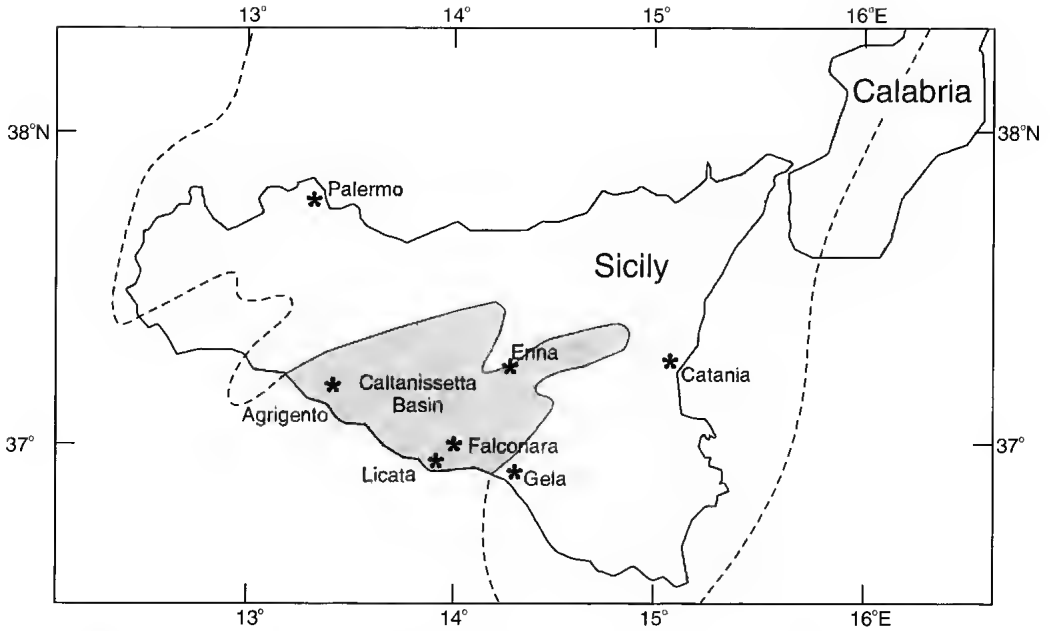

FIG. 1. — Location map, showing the geographical position of the Falconara Section. The shaded area represents the Caltanissetta Basin, while the solid line depicts the paleo-shore line. Modified from Gautier (1994).

Cocco (1905) did the same with different lithologics (marls, tuffs, diatomites) outcropping at several Sicilian localities.

Several cruises of the Deep Sea Drilling Project (DSDP) and of the Ocean Drilling Program (ODP) have taken place in the Mediterranean Sea: DSDP Legs 13, 42, ODP Legs 107, 160 and 161, and biogenic opal bearing localities from the former Tethys Sea area have been reported on by several authors as: Sanfilippo (1971, 1974), Sanfilippo *et al.* (1973), Rio *et al.* (1989). All these authors failed to apply the standard radiolarian biostratigraphic scheme for tropical latitudes, or to establish a local one.

Biogenic opal is generally not well preserved in the Neogene sediments of the Mediterranean Sea (Dumitrica 1973; Riedel *et al.* 1985). The latter authors report on only eight deep-sea localities in the Mediterranean Sea where siliceous remains are present in isolated levels. Moreover, at several of these localities the radiolarians are scarce or present in only a few of the samples. Furthermore, the species that are used in the standard low latitude stratigraphical radiolarian scheme are found in low numbers and are often morphologically different from the true oceanic ones.

Messinian siliceous diatomitic oozes outcrop at many localities in the Caltanissetta Basin, Sicily. These sediments yield abundant and diversified radiolarian faunas, thus having a potential for the compilation of a new local radiolarian stratigraphy based on acme zones and peak occurrences, through calibrations with other microfossil groups. As we could not apply the standard low latitude biostratigraphical radiolarian scheme to the Falconara Section, we used Q-mode factor analysis to facilitate faunal comparisons between samples as an alternative tool for correlation. This allows us to recognise, through time, different associations being indicative of specific ecological settings (i.e. peak occurrences), events that later may be used as a correlation tool both within the Falconara Section and between other sections in the Caltanissetta Basin.

Hilgen & Krijgsman (1999) stress the uncertainty and controversy about both the age of the Tripoli Formation and the origin of the cyclic bedding (Gautier *et al.* 1993; Butler *et al.* 1995; McClelland *et al.* 1996; Sprovieri *et al.* 1996; Vai 1997). They also summarise the following scena-

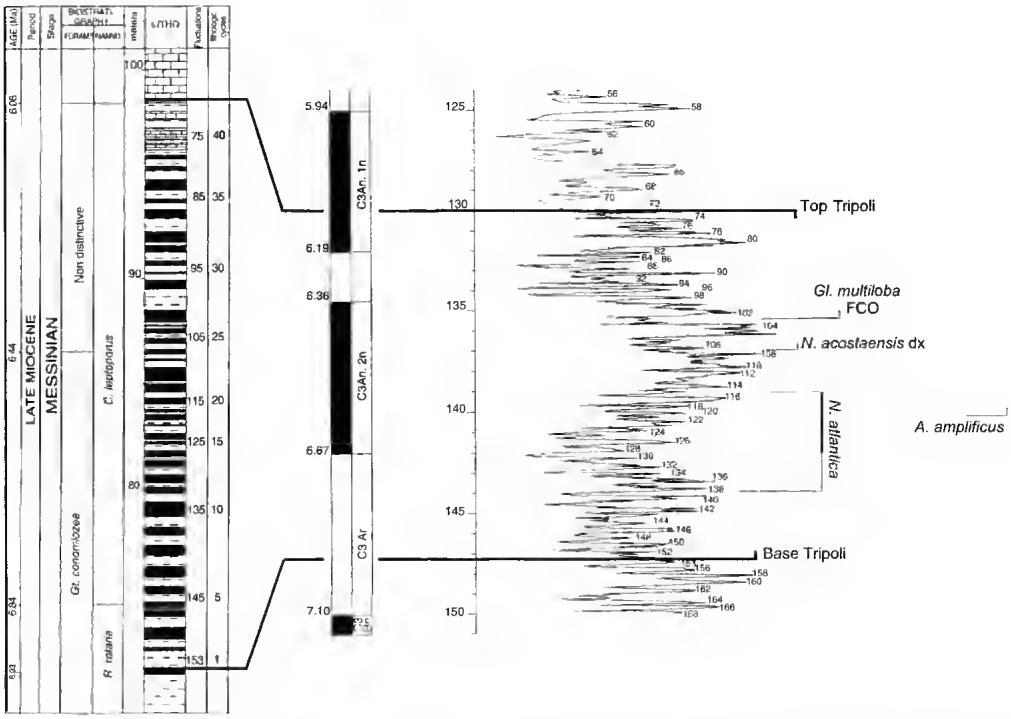

FIG. 2. — Correlation between Sprovieri *et al.* (1996) field-log for the Falconara Section, the polarity time-scale and the variations of the Cp/Rp (the two nannofossil species *Coccolithus pelagicus* and *Reticulofenestra pseudoumbilicus*) ratio at ODP Site 552. Selected bio-markers are also shown. Modified from Sprovieri *et al.* (1996).

rios to explain the cyclic diatomite formation as a result of: (1) the intensification of Atlantic inflow due to glacio-eustatic sea-level changes (Van der Zwaan & Gudjonsson 1986); (2) periodic upwellings (Gersonde 1980); (3) surface water warming (Broquet *et al.* 1981); (4) increased continental run-off (Meulenkamp *et al.* 1979); (5) global sea-level rise in combination with enhanced upwelling (McKenzie *et al.* 1979); (6) pulsating tectonics (Pedley & Grasso 1993).

With the uncertainty of the age of the Tripoli Formation and the exact origin of the cyclic bedding, Hilgen & Krijgsman (in prep.) conclude that the substitution of sapropel cycles by Tripoli diatomite cycles point to an orbital control on the sedimentary cyclicity, since sapropels are astronomically controlled (Hilgen *et al.* 1995; Sprovieri *et al.* 1996).

The palaeoclimatic interpretation of the diatomite-claystone couplets however, differs strongly from author to author. Sprovieri *et al.* (1996) suggest, based on planktonic foraminifers, that the deposition of claystones (or sapropels by some authors) took place during cold periods, while a warmer planktonic foraminifers assemblage is present in the diatomites. Müller (1985) concludes, based on nannofossil warm water species, that the claystones were deposited during warm periods, while diatomites reflect the influence of cold periods and upwelling. Hilgen & Krijgsman (1999) conclude that the diatomites (laminites) correspond to the precession minima and summer insolation maxima, and that the homogenous marls correspond to precession maxima and insolation minima.

The main goal of this paper is to examine the polycystine radiolarian fauna in the biosiliceous deposits in the Tripoli Formation as it outcrops at Falconara, Sicily (proposed by Colalongo *et al.* 1979) as a potential reference section for the Tortonian/Messinian boundary). The radiolarian

fauna is rich and well-preserved in most diatomites in the section and the radiolarian response to the cyclic changes are promising for a high-resolution biostratigraphic and correlation tool, as the radiolarian assemblages show major and significant changes between and within selected cycles (bulk radiolarian abundance, radiolarian flux, relative abundance of selected species, factor loadings, Spumellaria/Nassellaria ratio, etc.). These severe assemblage changes in the radiolarian fauna in the biosiliceous sediments at Falconara may provide information to improve and better understand the oceanographical and ecological evolution of the area.

STRATIGRAPHIC FRAMEWORK

In recent years Hilgen (1991), Langereis & Dekker (1992), Gautier *et al.* (1994), Suc *et al.* (1995), and Sprovieri *et al.* (1996) have been working on sediments of Messinian age in Sicily, while Hodell *et al.* (1994) worked up an age equivalent section in Morocco.

Hodell *et al.* (1994) convincingly demonstrated a high-resolution isotope, carbonate, magnetostratigraphic, and biostratigraphic record of a part of the Bou Regreg Section in north-western Morocco. The investigated drill core covered the time span from paleomagnetic Chron C4n partim to C3r (earliest Gilbert). This represents the time leading to and including the isolation and desiccation of the Mediterranean, i.e. the Messinian salinity crisis. They demonstrated that during Chrons C3An and C3Ar (6.935 to 5.894 Ma) the isotope and carbonate signals displayed a quasi-periodic variation with estimated periods of 40 and 100 kyr respectively. The *c.* 40 kyr period $\delta^{18}O$ signal was interpreted to reflect changes in the global ice volume caused by obliquity-induced changes (41 kyr period) in solar insolation in polar regions. They also concluded that the 100 kyr period carbonate variations were probably related to a long term modulation of the amplitude of the precessional cycle (*c.* 21 kyr period) which was not resolved due to their low sampling frequency.

The Falconara Section was first published by Catalano & Sprovieri (1971). D'Onofrio *et al.* (1975), Colalongo *et al.* (1979), van der Zwaan (1982), and Theodotites (1984) published on the calcareous plankton biostratigraphy in this section. Gersonde (1980) and Gersonde & Schrader (1984) reported on the diatom biostratigraphy, while stable oxygen and carbon isotope data were provided by van der Zwaan (1982), and van der Zwaan & Gudjonsson (1986).

Langereis *et al.* (1984), Hsü (1985), and Langereis & Dekker (1992) did not succeed in establishing a paleomagnetic stratigraphic framework for the section, while Gautier *et al.* (1994) claimed to have obtained paleomagnetic results from the Tripoli Formation.

Sprovieri *et al.* (1996) rejected the paleomagnetic results from Falconara proposed by Gautier *et al.* (1994). Instead they correlated the paleomagnetic record of ODP Site 552 (North Atlantic) with ODP Site 654 (Thyrrenian Sea), after having reinterpreted the magnetostratigraphic boundaries and their ages according to the magnetic polarity reversals record proposed by Cande & Kent (1992, 1995). The abundance fluctuations in the *Globigerinoides* sp. population at Site 654 were then correlated to the record of the same fluctuations in the Falconara Section.

ODP Site 552 from the North Atlantic was used by Sprovieri *et al.* (1996) to obtain the paleomagnetic boundary ages of Chron 3An by using the nannofossil abundance fluctuations published by Beaufort & Aubry (1990). Site 552 provides a complete sequence of abundance fluctuations (Fig. 2), forced by the astronomical precession cycles from the middle late Tortonian to the base of Zanclean. Sprovieri *et al.* (1996) were able to accurately correlate sedimentary and biostratigraphic events recorded in the Mediterranean basin with similar events in the North Atlantic (Site 552), and demonstrated that the ages could be estimated by comparison with the sequence of abundance fluctuations linked to the precession cycle. By this technique Sprovieri *et al.* (1996) estimated the base and top of the Tripoli Formation at Falconara to be 6.93 Ma and 6.08 Ma respectively (Fig. 2), which is the age model adopted in our present paper.

This deviates significantly from the age model provided by Hilgen & Krijgsman (in prep.).

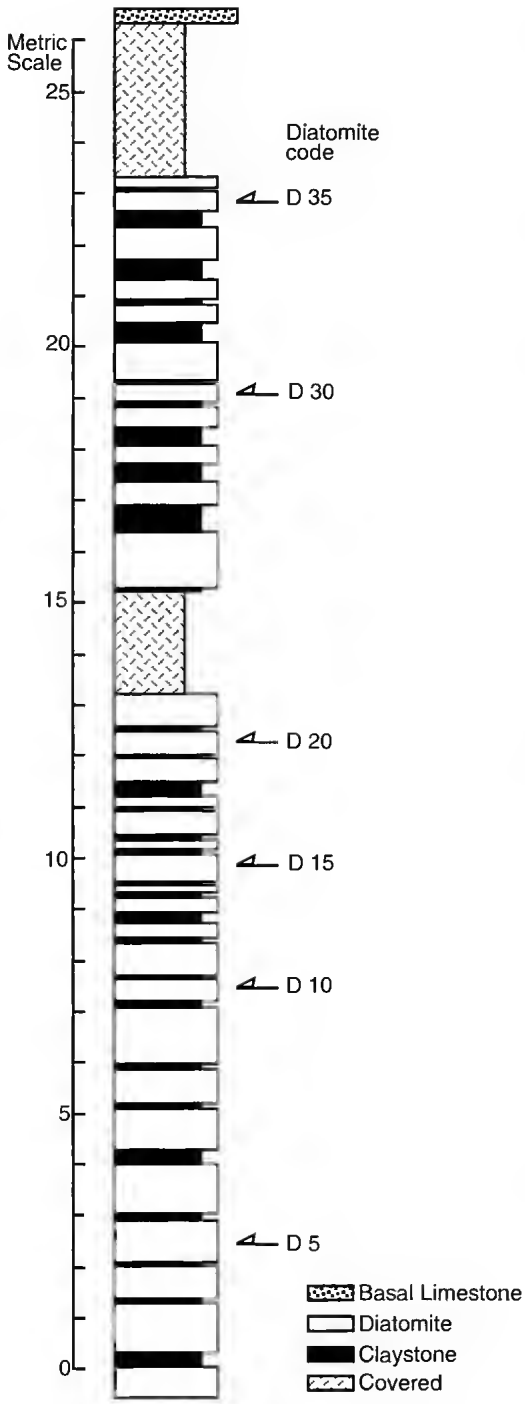

FIG. 3. — The 1995 field-log for the Falconara Section.

They used the position of the first and last occurrence of the planktonic foraminifer *Globorotalia nicolae* as the starting point for their tuning experiment. These events have been astronomically dated at 6.829 and 6.72 Ma in sections on Crete and Northern Italy (Hilgen *et al.* 1995; Krijgsman *et al.* 1997) and are located in the Tripoli cycle T9 and T14, respectively. With these ages as the starting point, all diatomite cycles have been tuned to the $La90_{(1,1)}$ precession and summer insolation time series (Hilgen & Krijgsman 1999). They provide absolute ages for all sedimentary cycles based on their astronomical calibration, resulting in 7.008 and 5.99 Ma for the base and the top of the Tripoli Formation. According to this new age model the Falconara Section starts with Tripoli cycle T8 (6.847 Ma) and contains 41 cycles (Hilgen & Krijgsman 1999), suggesting that Sprovieri *et al.* (1996) are missing seven Tripoli cycles. In future work, we will use the new age model of Hilgen & Krijgsman (1999). In Table 8 we have tabulated the sample ages according to Sprovieri *et al.* (1996) and indicated the correlation to the Tripoli cycles and absolute ages according to Hilgen & Krijgsman (1999).

MATERIAL AND METHODS

The study area covers the valley and hilly region delimited by the Sicani, Madonie and Erei Mountain Ranges (SW Sicily, Southern Italy), roughly coinciding to the Agrigento and Caltanissetta provincial territory (Fig. 1). Hitherto the best known Tertiary marine opal bearing sediments on Sicily are included in the Tripoli Formation, the so called diatomites or laminites, which are nicely exposed in the Falconara Section.

Our sampling program (May-June 1995 and August 1997) concentrated on the Messinian portion of the 27 m thick Falconara Section (Fig. 3). In 1995 we sampled a total of 30 out of 41 diatomites and 18 out of 41 claystones, (Table 2) and the remaining lithologies were sampled in 1997. The diatomites in Cycles 7, 21 and 28 were continuously sampled and are inclu-

ded in this work. The sampling of the Falconara Section resulted in two different sample sets: (1) one central sample per lithological unit for the 49 sampled lithologies; (2) one consisting in a continuous sampling of all the diatomites observed in the field. The maximum number of samples for a single diatomite was 48, resulting in a time-resolution of a few hundred years only.
In the Tripoli Formation Sprovieri *et al.* (1996) referred to the lithological levels and labelled the diatomites from T1 to T41 and the intercalated claystones from M1 to M42, with every negative or positive fluctuation in the nannoplankton flora representing a half-cycle. The claystones are arbitrarily assumed to represent the base of the cycles.
We have processed a total of 162 samples (Tables 2-5) from the Falconara Section and made slides for quantitative and qualitative analyses following the method proposed by Goll & Bjørklund (1974).
We selected the sample from the central part of each sampled lithological unit for both the diatomites and the claystones, assuming it to be representative for that lithology. All samples were analysed for their content of total organic carbon (TOC) and calcium carbonate by the use of an infrared gas analyser (LECO). This instrument measures, by infrared absorption, the amount of CO_2 released from the samples during combustion. The $CaCO_3$ content was calculated by the difference of C_{total} and $C_{carbonate\text{-}free}$ multiplied by the factor of 8.3 (atomic weight ratio of $CaCO_3$ to carbon).
Samples from within a single cycle have been coded, when plotted (Figs 7-12), as XX.YY [XX indicates the reference number for the cycle (Tables 3-5) and YY indicates the position of the sample within the cycle, given as a percentage of the time elapsed from the bottom of the cycle]. This has been done in order to simplify comparisons between different cycles, based on the assumption that the deposition of each cycle was influenced by the precession cycle, and therefore took place over an average time span of 21000 years (as demonstrated, for the Falconara Section, by Hilgen *et al.* 1995; Sprovieri *et al.* 1996). As a working hypothesis we had to assume that the sedimentation rate was constant throughout the cycle, in order to calculate

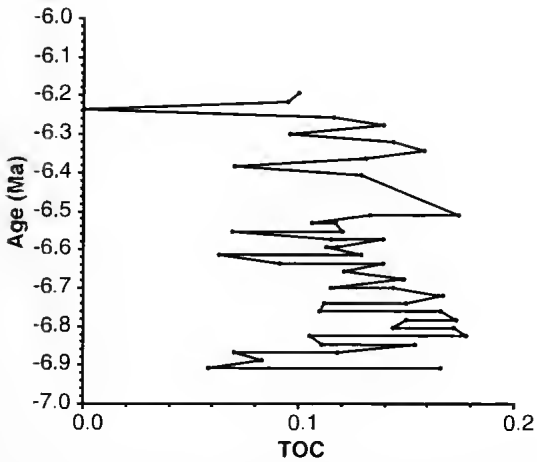

FIG. 4. — TOC (Total Organic Carbon) measurements through the section.

sample ages. Flux estimates are therefore based on the assumption that the deposition of each cycle took place over 21,000 years. These calculations were carried out on sediment cubes 2 × 2 × 2 cm.
The Factor Analysis Method (Imbrie & Kipp 1971) and the Fortran program CABFAC (Klovan & Imbrie 1971) were used for the statistical treatment of the data set. The Cabfac Q-Mode factor analysis program was used for grouping the samples in the Falconara Section into varimax assemblages based on the similarity between samples. This is done by transforming the raw data into variables (the factor components), each of which has a set of values (the varimax factor scores) giving an indication of which species are most important in each factor.
The species that were treated statistically had to occur as more than 2% of the total fauna in at least one sample, as recommended by Imbrie & Kipp (1971). This reduced the original 68 morphotypes (Table 1) counted during this study to 41 morphotypes used in the first factor analysis run. A selection of the morphotypes included in our factor runs are shown in Figs 20-22.

RESULTS

The organic carbon values from the central part

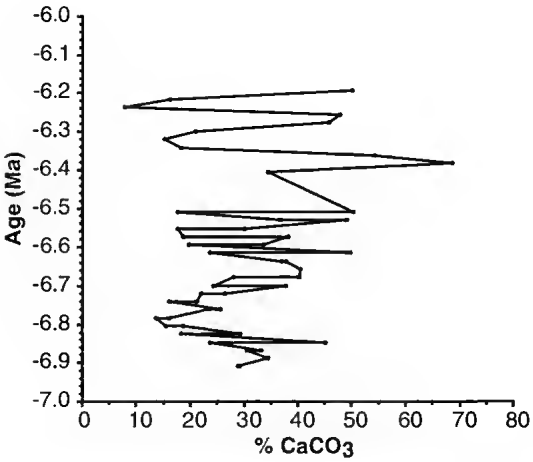

FIG. 5. — Percent of $CaCO_3$ through the section.

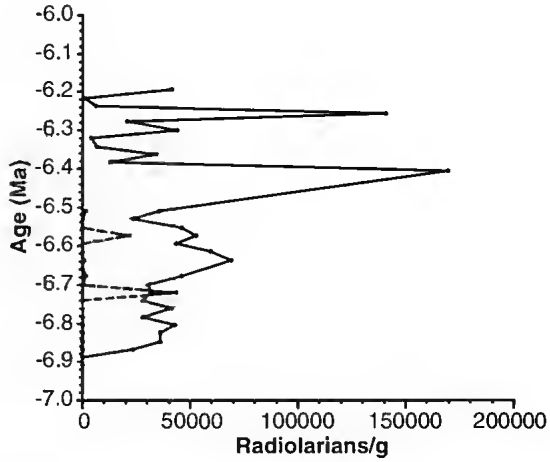

FIG. 6. — Number of radiolarians per gram bulk sediment in the diatomites through the section. Dashed line refers to claystones.

of the 49 lithologies (Table 2, Fig. 4) from Falconara are low, 0.06 < TOC < 0.18%, throughout the section. These low values are in good agreement with Brosse & Herbin (1990) who also reported on values much lower than 1% TOC in the upper Messinian of ODP Sites 654A and 652A in the Thyrrenian Sea. The $CaCO_3$ values (Table 2, Fig. 5) show fluctuations between 7.92 and 50.09%.

The abundance of radiolarian specimens in the 49 studied lithologies ranges from zero in Cycle 2 till more than 169000 radiolarians/g bulk sediment in Cycle 26 (Fig. 6), therefore indicating that the different cycles display marked variations in the total abundance of radiolarian specimens and in the species composition as demonstrated by the changes in factor loadings, as we will show later (Figs 15-19, Tables 6-8).

Our data show that radiolarians are usually not present in the claystones (Table 2, Fig. 6), as also documented for the diatoms (Gersonde 1980; Gersonde & Schrader 1984). Of our 19 claystones, nine were barren for polycystine radiolarians, while eight had low numbers, less than 3,000 radiolarians/g carbonate free sediment. However, two claystones had significant high numbers, more than 43,000 (S11) and about 21,500 (S18) radiolarians/g bulk sediment.

The abundance of radiolarian skeletons is showing great changes between the different diatomites (Fig. 6). To test how the radiolarian abundance changed within a cycle and between cycles, we arbitrarily selected three continuously sampled diatomites, the lowest at *c.* 5 m, the middle at *c.* 12 m and the uppermost at *c.* 18 m into the section, respectively:

Cycle 7. (Figs 7, 10; Table 3): diatomite D7, in the lower part of the section, is 46.9 cm thick and the claystone/diatomite boundary is 46.6% into the cycle. This percentage notation has been adopted in order to have a way to directly compare the data obtained from different cycles, with the assumption that the sedimentological evolution of each cycle is the same.

Cycle 21. (Figs 8, 11; Table 4): diatomite D21, in the middle of the section, is 64 cm thick and the claystone/diatomite boundary is about 11% into the cycle.

Cycle 28. (Figs 9, 12; Table 5): diatomite D28, in the upper part of the section, is 49.7 cm thick and the claystone/diatomite boundary is about 49.2% into the cycle.

In the three cycles chosen in this experiment, the abundance of radiolarians varies between *c.* 3,200 in Cycle 28 and *c.* 117,000 radiolarians/g bulk sediment in Cycle 7. We have no calcium carbonate data for the continuous sampled diatomites but the variation patterns of the radiolarian abundance number within the three cycles are however distinct (Figs 7-9).

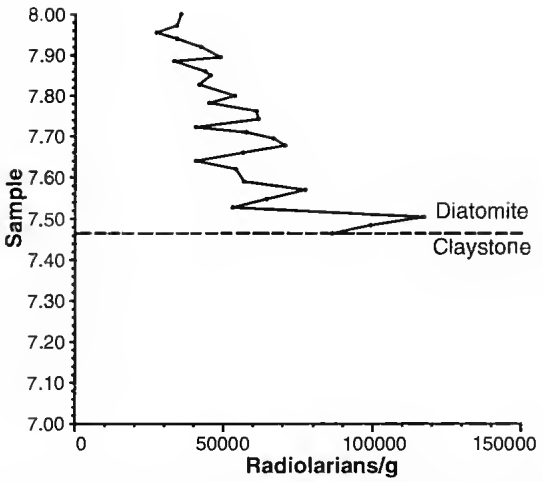

FIG. 7. — Number of radiolarians per gram bulk sediment through Cycle 7. The dashed horizontal line marks the transition between claystone and diatomite.

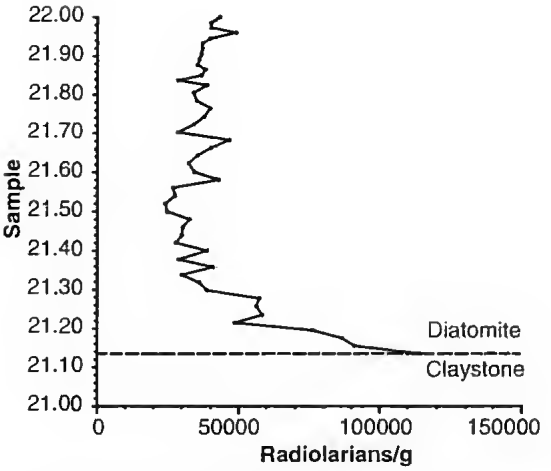

FIG. 8. — Number of radiolarians per gram bulk sediment through Cycle 21. The dashed horizontal line marks the transition between claystone and diatomite.

In the following we will discuss only the diatomites from the three selected cycles.

Cycle 7. Radiolarians are present with highest abundances (Fig. 7) in the lower 10% of the diatomite (*c.* 117,000 radiolarians/g bulk sediment), while the number gradually decreases towards the top of the diatomite (*c.* 27,200). As can be seen from the Spumellaria/Nassellaria (S/N) ratio, spumellarians are dominating over nassellarians in the bottom five samples (with one exception), while in the rest of the diatomite the S/N ratio fluctuates around a value of 0.7, indicating a dominance of nassellarians (Fig. 10).

Cycle 21. Radiolarians are present with highest abundances in the lower 10% of the diatomite (*c.* 114,000 radiolarians/g bulk sediment). This number rapidly decreases to *c.* 40,000 *c.* 20% into the diatomite, thereafter it fluctuates from between *c.* 24,000 and 49,000 towards the top (Fig. 8). In the lower 15% of the diatomite (with the exception of the oldest sample), the S/N ratio is higher than one, while for the remaining part of the diatomite nassellarians are the dominant group (Fig. 11).

Cycle 28. Radiolarians are present with highest abundances in the lower 10% of the diatomite (*c.* 55,000 radiolarians/g bulk sediment). This number rapidly decreases to less than 10,000 *c.* 15% into the diatomite, thereafter it remains almost constant (Fig. 9). In this diatomite the spumellarians are dominant throughout, in contrast to the previous two cycles, where nassellarians are the dominant group. In the topmost 20% of the diatomite the S/N ratio fluctuates between 10 and 65 (Fig. 12).

In order to take the dilution effect of carbonate into consideration we plotted the number of radiolarians/g carbonate free sediment of the central sample from all lithologies (Fig. 13). We have sampled 19 out of 41 claystones and only two have a significant radiolarian content, between 30,000 and 50,000 radiolarians/g carbonate free sediment, while two diatomites have values reaching more than 250,000 radiolarians/g carbonate free sediment.

The distorting effect of the (most likely changing) sedimentation rate through the section was then considered, and we calculated a radiolarian flux curve for the section (Fig. 14), accepting the diatomites and claystones to be precession controlled, with an average duration of 21,000 years. This curve depicts the changes of the number of radiolarians per time- and per surface-unit (e.g., number of radiolarians/kyear/cm^2), thus being an image of the changes in radiolarian productivity through time, which is independent both from the composition and

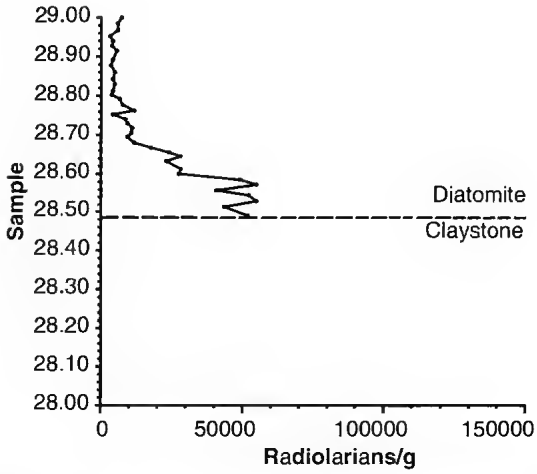

FIG. 9. — Number of radiolarians per gram bulk sediment through Cycle 28. The dashed horizontal line marks the transition between claystone and diatomite.

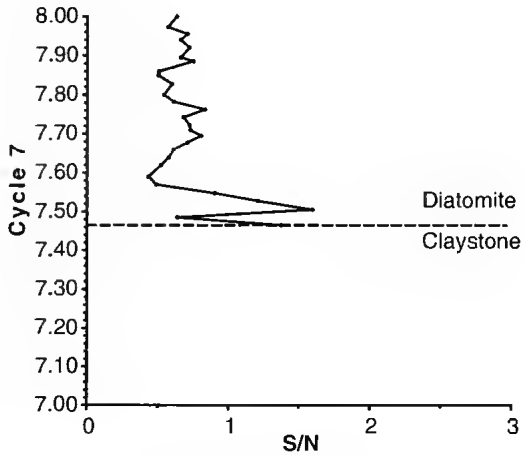

FIG. 10. — S/N ratio through Cycle 7. The dashed horizontal line marks the transition between claystone and diatomite.

from the accumulation rate of the sediment hosting the microfossils. It is apparent that only one diatomite (D26) represents one major high production pulse with an outstanding radiolarian flux (304,000 radiolarian skeletons/kyear/cm^2) when compared to the rest of the diatomites (Fig. 14; Table 2). This abundance peak is a potential event to be used as a key-level in local and regional correlation.

The application of Q-mode factor analysis to a total of 41 morphotypes resulted in 10 factors (polycystine radiolarian associations), explaining a cumulative variance of 95.89% (data from this run are not presented herein).. The 13 morphotypes having a varimax factor component value higher than 2.000 (i.e. the most "important" species for each factor) in this run were then used once again in a second factor analysis run. The results between the two runs are not significantly different, therefore enabling us to work with only 13 rather than the 68 morphotypes that we started out with. This reduction in species will speed up the counting time, and this technique can, therefore be a potentially useful tool for correlation. The screening (the first factor run) and reduction to only the 13 most important morphotypes will make it easier to compare and use data from other authors. Of the factor component peaks resulting from this run we tabulated in Table 8, 46 factor component values higher than 0.400 (Table 6).

Factor 1 (dominated by the *S. delmontensis* group, Table 7) reaches high values in different portions of the section, but is more significant in sediments older than 6.50 Ma (Fig. 15).

Factor 2 (dominated by Larcoidea sp., Table 7) is common throughout the section becoming more important in sediments younger than 6.54 Ma (Fig. 16).

Factor 3 (dominated by *Lithomitra lineata*, Table 7) is the only factor that gives a good opportunity to split the Falconara Section in a higher and lower portion, as high values for this factor are only found in the lower portion of the section, in sediments older than 6.60 Ma (Fig. 17).

Factor 4 (dominated by *Didymocyrtis* sp., Fig. 18; Table 7) is one factor assigned to the claystones, peaking in S13 and S16. On the quantitative slide of sample S16 no radiolarians were found (Table 2), however, on the enriched fauna slides an almost monospecific *Didymocyrtis* sp. assemblage occurred.

Factor 7 (dominated by *Anthocyrtidium ehrenbergi*, Fig. 19; Table 7) is the second factor assigned to the claystones with one peak in S21.

DISCUSSION

The Falconara Section is peculiar in its radiolarian assemblage and species morphology. These

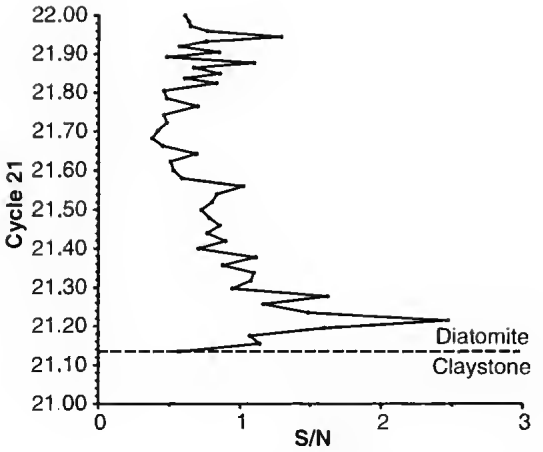

FIG. 11. — S/N ratio through Cycle 21. The dashed horizontal line marks the transition between claystone and diatomite.

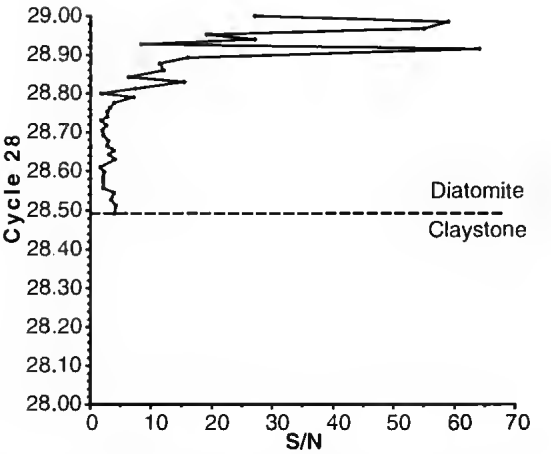

FIG. 12. — S/N ratio through Cycle 28. The dashed horizontal line marks the transition between claystone and diatomite.

deposits are immediately pre-dating the isolation and desiccation of the Mediterranean Sea, causing "stressed" ecological conditions for the plankton. The following scenarios have been used to explain the cyclic diaromite formation, events that can also cause these stressed ecological conditions: (1) the intensification of Atlantic inflow due to glacio-eustatic sea-level changes (Van der Zwan & Gudjonsson (1986); (2) periodic upwellings (Gersonde 1980); (3) surface water warming (Broquet *et al.* 1981); (4) increased continental run-off (Meulenkamp *et al.* 1979); (5) global sea level rise in combination with enhanced upwelling (McKenzie *et al.* 1979); (6) pulsating tectonics (Pedley & Grasso 1993). Hilgen & Krijgsman (1999) point out that the Miocene sapropels had the same origin as the Pliocene-Pleistocene ones, namely dominantly precession controlled "dry-wet" oscillations in the circum-Mediterranean climate. These alternations certainly caused differences in the living conditions for the marine microplankton.

The age of the Tripoli Formation exposed in the Falconara Section was determined by Hilgen & Krijgsman (1999) to range from 6.847 to 5.980 Ma, starting with Tripoli Cycle T8, compare Sprovieri *et al.* (1996) giving the range of 6.93 to 6.08 Ma, corresponding to the nannofossil *C. leptoporus* zone. The standard radiolarian zonation cannot directly be applied to the Mediterranean Sea, nor to the Messinian siliceous deposits on Sicily.

The base of the radiolarian *Stichocorys peregrina* zone is defined as the transition from *S. delmontensis* to *S. peregrina*, dated to occur at *c.* 6.2-6.3 Ma (Theyer & Hammond 1974). Riedel *et. al.* (1974) reported on one radiolarian-rich sample in the Trubi marls of the Capo Rossello, assigned to the Zanclean stage, lower Pliocene, stating: "...the "Trubi" assemblage is to be placed between the time of evolutionary transition from *S. delmontensis* to *S. peregrina*, and that from *Spongaster berminghami* to *S. pentas*, and thus evidently belongs to the *Stichocorys peregrina* zone." From the same profile Riedel & Sanfilippo (1978) also report on common typical oceanic specimens of *S. peregrina* with truncated-conical third segment.

In the Falconara Section, assigned to the older Tripoli Formation, we have not been able to observe this transition. We include in the *S. delmontensis* group several morphologies, some with a thick silicified test, others with a very thin test, and several forms having irregularly shaped segments with tilted strictures between segments. No real specimens of the oceanic form of *S. peregrina* have been observed in our material. We therefore assign the section to predate the *Stichocorys peregrina* zone.

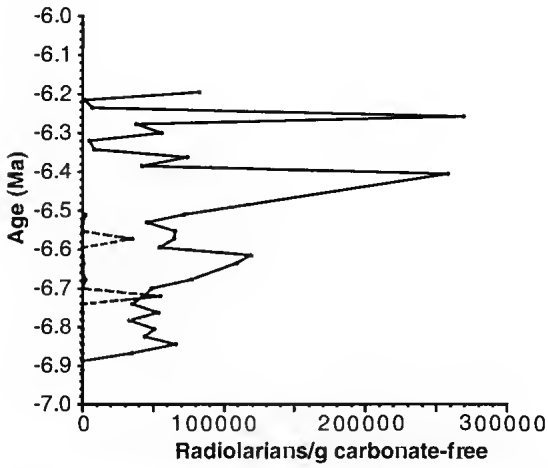

FIG. 13. — Number of radiolarians per gram $CaCO_3$-free in the diatomites through the section. Dashed line refers to claystones.

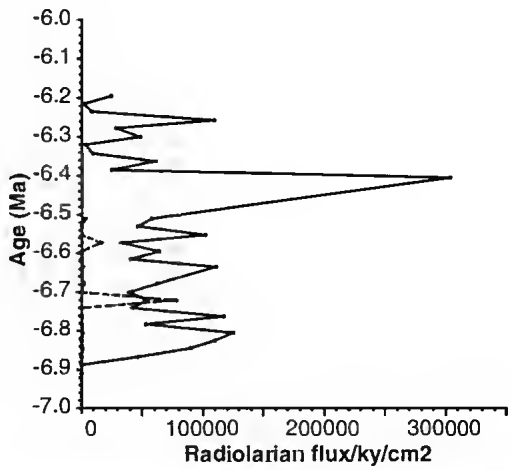

FIG. 14. — Radiolarian flux (number of radiolarians/kyear/cm^2) through the section. Dashed line refers to claystones.

Foraminiferal assemblages are generally present in the diatomites with a rich and diversified fauna, while the diversity is generally lower in the claystones. In some claystone units the foraminiferal assemblages are missing, e.g., M30, M41, and M42 (Sprovieri *et al.* 1996). They suggest that the claystones are deposited during cold periods while the diatomites are deposited during warm periods, as they generally have a warmer planktonic foraminifer assemblage.

Müller (1985) on the other hand concludes the opposite. The claystones have a higher amount of nannoplankton and a more diversified assemblage with input of warm water species (i.e. *Sphenolithus abies*) and some discoasters. She therefore concluded that the claystones were deposited during warm periods, while the diatomites were formed during cold periods and times with upwelling related to changes in the prevailing wind direction.

The *Sticochorys delmontensis* group is present throughout the section and varies greatly in abundance as well as morphology, as also observed in the Gibliscemi Section (Caulet pers. comm. 1997). The variation in the skeletal morphology in the *S. delmontensis* group is a potential tool in interpreting the paleoclimate if we can decode the meaning of these variations.

The *S. delmontensis* association (Factor 1, Fig. 15) and *Lithomitra lineata* association (Factor 3, Fig. 17) show almost the same pattern of major and rapid variations in the lower part of the section, older than 6.5 Ma, interpreted as rapid ecological changes over very short time intervals.

In Factor 2 Larcoidea sp., *Porodiscus* sp., and *Spongotrochus glacialis* are the dominant taxa, after 6.5 Ma and modern equivalents of these categories are often found in deeper and cooler water, except for *Stylochlamidium venustum* (forms that we included in the *Porodiscus* sp.) showing a shallow and warm water affinity in the Pacific (Mullineaux & Westberg-Smith 1986). As the modern equivalents of these groups do refer to open ocean conditions, it is not easy to interpret the Falconara Section in a scenario where the shallow Caltanissetta basin has a restricted communication with the ocean.

Diatoms are generally absent or badly preserved in the claystones (Gersonde 1980; Gersonde & Schrader 1984). Similarly for the radiolarians, but two claystones have significant amounts of radiolarians, S18 (21,500 radiolarians/g bulk sediment) and S11 (43,000 radiolarians/g bulk sediment). In addition three claystones are characteristic by their fauna associations, S13 and S16 (by Factor 4, dominated by *Didymocyrtis* sp.) and S21 (by Factor 7, dominated by *Anthocyrtidium ehrenbergii*). These five levels are potential good local or regional markers within the Caltanissetta basin.

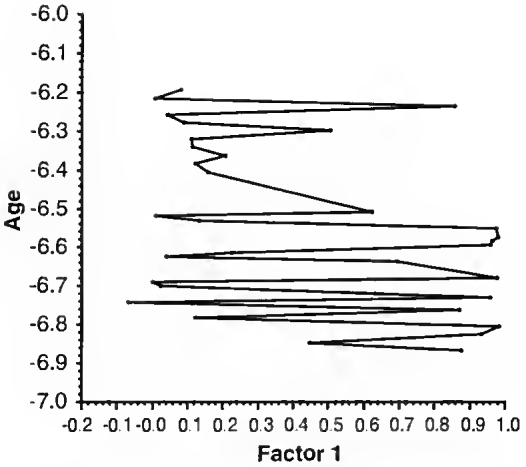

FIG. 15. — Factor components through the section (Factor 1).

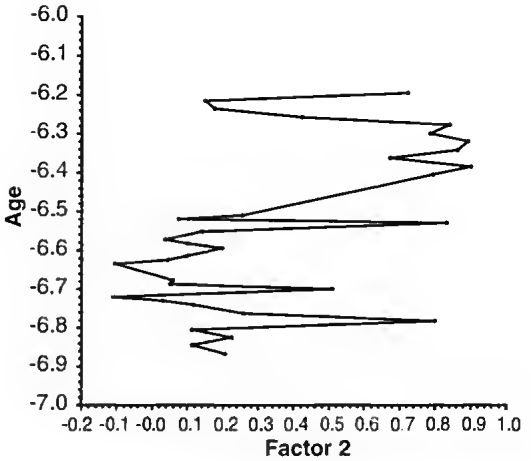

FIG. 16. — Factor components through the section (Factor 2).

The *Didymocyrtis* sp. is almost monospecific and as the section is predating the *Stichocorys peregrina* zone, the *Didymocyrtis penultima* zone would seem natural, but we cannot assign our assemblage to this zone with certainty. This form of *Didymocyrtis* sp. might be the oceanic counterpart of *Didymocyrtis penultima*, however, it differs so much that it probably is a new species. We do not think that this morphology is simply a result of different ecology and corresponding ontogenesis.

The diatomites show great variation in the number of radiolarians/g sediment, both between the different diatomites and within them (Figs 6-9). To test the hypothesis if there is a rhythmic development through time between the different diatomites, we assigned each sample to its time equivalent position within each cycle, assuming a claystone and a diatomite couplet to represent 21,000 years. Each claystone and diatomite has its own polycystine radiolarian "fingerprint" (assemblage or event) as determined by the percent distance into the cycle. This will provide an excellent stratigraphic tool with a high and precise time resolution (Table 8).

Another "fingerprint" that can help to recognise the different diatomites is the Spumellaria/Nassellaria (S/N) ratio. D7 and D21 show a very similar and systematic evolution in this ratio, where spumellarians dominate the lower part of the cycle, while the nassellarians take over in the upper part of these cycles (Figs 10-11). D28 shows a different trend in the Spumellaria/Nassellaria ratio since the spumellarians are always dominant and they become much more so in the upper part of the cycle (Fig. 12).

The differences in the polycystine radiolarian "fingerprint" between cycles cannot be explained at present, but only speculated upon. The microfauna of the Tripoli Formation, both at Capodarso (Suc *et al.* 1995) and at Falconara (Sprovieri *et al.* 1996) is rich in planktonic foraminifera, a typical oceanic imprint. The sedimentation history of the Caltanissetta basin has changed through the Messinian, as documented by the alternation of diatomites and claystones due to processes causing the isolation, changes in production and preservation of organic material, changes in primary and secondary production, and desiccation of the basin, compare the scenarios outlined elsewhere. Suc *et al.* (1995) point out that the diatomite-claystone couplets are a result of sea-level fluctuations. Sprovieri *et al.* (1996) on the other hand concluded that the rhythmites are astronomically forced due to the 21,000 yrs periodicity based on the occurrence of planktonic foraminifers, as also supported by Hilgen *et al.* (1995) and Hilgen & Krijgsman (1999).

Whatever causes the rhythmites, the presence or

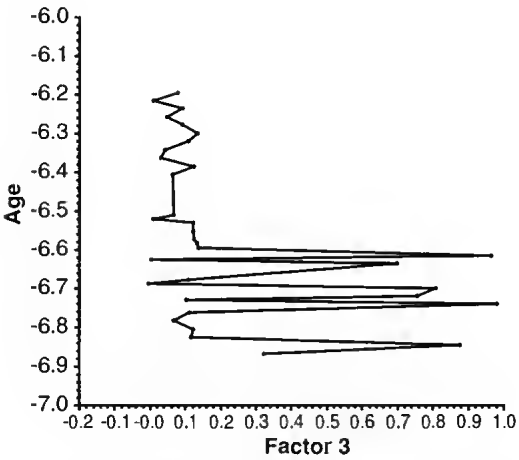

FIG. 17. — Factor components through the section (Factor 3).

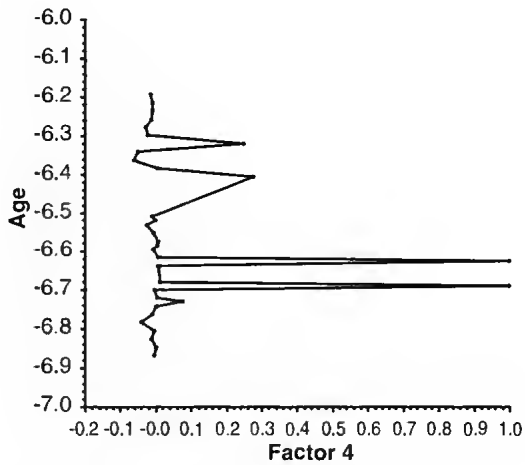

FIG. 18. — Factor components through the section (Factor 4).

absence of polycystine radiolarians is a result of changes in the ecological, as well as in the preservational conditions within the Caltanissetta Basin. Suc *et al.* (1995) concluded that the Contrada Gaspa Section, constituted by 108 m of sediments ranging from diatomites to clayey diatomites, was a result of deposition in a small basin intermittently isolated from the Caltanissetta Basin. The Falconara Section, near to the rim of the Caltanissetta Basin, has a different lithological structure than the Capodarso Section, therefore making correlations difficult.

This makes the Caltanissetta basin an analogue to modern Norwegian fjords. Polycystine radiolarians have been shown (Swanberg & Bjørklund 1986, 1987) to live and thrive in very landlocked environments such as fjords and polls, where they occur in the plankton in concentrations of *c.* 10000 radiolarians/m^3 seawater. In one poll the assemblage is almost monospecific (*Amphimelissa setosa*) showing a different skeletal morphology than the oceanic counterpart period Bjørklund & Swanberg (1987) suggested that in the warm end of its temperature range, in the fjords, the availability of nutrition gave a much higher growth rate that resulted in smaller and reticulated forms, while the oceanic forms, in the cold end of its temperature range, grew slower and over a longer time period, resulting in a larger and more silicified skeleton with rounded pores. An analogue is the *S. delmontensis* in the Caltanissetta Basin which shows a big variation in its morphology, where we identified and counted four different morphotypes. It is apparent that in certain parts of the section, and even in certain parts within the single diatomites, the different morphologies of *S. delmontensis* must be a response to ecological changes. The "dry-wet" oscillations in the Mediterranean climate and the enhanced continental run-off (Meulenkamp *et al.* 1979) must certainly be kept in mind.

The high neritic plankton values are in conflict with the general understanding that radiolarians are not abundant in the neritic environments. In the fjord sediments 1,000 polycystine radiolarians/g is a normal value, as the terrigenous input due to river discharge is high and the microfossil remains are very much diluted.

The Caltanissetta Basin, if compared with a fjord situation, must be of a different magnitude and structure. Terrigenous sediments must be trapped in near land "sub-basins" with the possibility to produce, accumulate and preserve biogenic sediments rich in both carbonate and opal microfossil remains, probably the Caltanissetta basin was more open than the analogue fjords.

High levels of organic material and opal microfossils are, however, deposited in present day anoxic basins such as in the Tyro Basin in the eastern Mediterranean (Bjørklund & de Ruiter

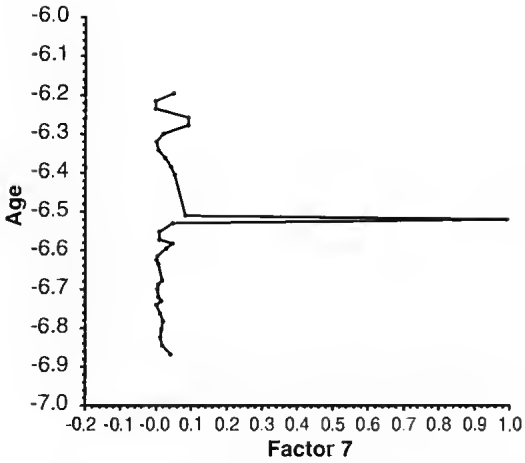

FIG. 19. — Factor components through the section (Factor 7).

1987) in contrast to the oxygenated sediments in the Mediterranean proper (Caulet 1974) which are poor in opal microfossils.

The Spumellaria/Nassellaria ratio has been used as a potential tool to discriminate between assemblages in neritic environments (Palmer 1986) where spumellarians predominate the plankton, *vs* open oceanic environments where nassellarians tend to be the dominant group (McMillan 1979, 1981). Swanberg & Bjorklund (1987) clearly demonstrated that the radiolarian fauna of Sogndalsfjorden was dominated by early developmental stages of *Amphimelissa* sp. which comprised 11%, 39% and 60% of the plankton fauna proceeding from the outer to the inner fjord basin. In two other landlocked basins the same species made up 91 and 99% of the fauna. This clearly demonstrates the occurrence of nassellarians with more than 99% in the neritic plankton, in opposition to the conclusions by Palmer (1986) and McMillan (1979, 1981), and does not signal open ocean conditions.

If our detailed investigation of the S/N ratio in the three different cycles (Figs 10-12) should be interpreted as depicting neritic and oceanic conditions, both D7 and D21 would then show a gradual evolution from neritic to oceanic conditions as they are dominated by spumellarians close to the base of the diatomites, while nassellarians are increasing towards the top. The S/N ratio in D28 suggests on the contrary that this cycle was exclusively deposited in a neritic environment. We cannot see any direct connection between the S/N ratio and the neritic *vs* oceanic environments (distance from shore), as interpreted by Palmer (1986). The change in the S/N ratio is more subject to local ecological changes within the basin, and not so much a result of the sites position in relation to the coast or the open oceanic. Boltovskoy (pers. comm. 1997) also observed that the S/N ratio behaves inconsistently on different sediment types.

Our conclusion is therefore that the S/N ratio in the sediment cannot be used to discriminate between neritic *vs* oceanic conditions, mostly as this ratio is very sensitive to dissolution, a common problem in the hemipelagic province. Locally, however, the S/N ratio can be a useful stratigraphic tool to recognise polycystine distribution patterns, both within and between cycles in a section, as well as between sections. This because the S/N ratio in this scenario probably depicts changes and differences in the ecology and in the production, as well as in the accumulation and preservation conditions of microfossils.

The diatomites are generally very rich in radiolarians and we tend to conclude that nutrient availability in the basin during their formation is good, probably as a result of continental run off (Meulenkamp *et al.* 1979). The almost total lack of planktonic life in the claystone lithologies in the Capodarso Section (Suc *et al.* 1995) indicates that the absence of siliceous microfossils is not only a result of silica dissolution. Also planktonic foraminifers are absent or rare, while the benthic foraminifer fauna is restricted (Suc *et al.* 1995), indicating that an environmental stress is affecting the basin. The micro lamination do indicate periodic anoxic conditions.

Particularly high values of the factor component peaks for the final nine factors (higher than 0.400, framed in Table 6) were used to trace the most important "radiolarian factor peaks" throughout the section. The peaks (Table 8) are coded as X.Y, where X represents the factor number and Y represents a reference number for the "factor peaks", arranged in an ascending order from base to top of the section.

Some factors (Table 8, e.g., Factor 1) display "16

factor peaks" (framed values in Table 6) in different portions of the section (e.g., from diatomites D4 to D34), which have to be interpreted as the recurrence of equivalent ecological or hydrographical conditions at different times.

The peak pattern as presented in Table 8, is our first attempt to make a radiolarian stratigraphic synthesis of the Falconara Section based on "factor peaks", and the peak order obviously represent an evolution of the radiolarian assemblage as a response to changing environments. To use the peaks as a correlation tool between our reference section (Falconara) and another section we have to pick a sequence of factor peaks from the section we want to correlate and look for the same peak pattern in the reference section. We see this technique to be especially useful when correlating profiles in the same section where visual correlation is difficult due to tectonism.

CONCLUSIONS

1. In diatomites the number of radiolarians/g bulk sediment fluctuates between 1,200 (D35) and 169,500 (D26). One diatomite (D2) is barren.

2. On a $CaCO_3$ free basis, D26 has a flux of 303,500 radiolarian skeletons/kyear/cm^2. A possible regional marker for correlation.

3. In D7 and D21 spumellarians are dominant in the lower 10-15% of the diatomites, while nassellarians dominate the upper part.

4. In D28 spumellarians dominate the whole diatomite.

5. The S/N ratio reflects local ecological changes (as shown in D28).

6. In claystones the number of radiolaria/g bulk sediment is generally barren or low. Two claystones, S18 and S11, have high numbers of 21,500 and 43,000, respectively, and may serve as a correlation tool.

7. S13 and S16 have factor component peaks of 0.997 and 0.997 respectively, two claystones that may serve as a regional marker, dominated by an almost monospecific *Didymocyrtis* sp. (not *Didymocyrtis penultima*) assemblage.

8. S21 has a factor component peak of 0.993, *Anthocyrtidium ehrenbergii* is the important species, and may be a stratigraphical marker.

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APPENDIX

TABLE 1. — The taxa which have been identified and counted for the statistical exercise in this study. Literature references are given to illustrations of the most important taxa.

	Taxa	References for illustrations
1	*Botryopyle* sp.	Fig. 20A-E
2	*Acrobotrys* sp. cf. *A. disolenia*	Petrushevskaya (1981; fig. 495)
3	*Actinomma* sp. cf. *A. medianum*	Nigrini & Moore (1979; pl. 3, fig. 5)
4	*Actinomma* sp.	
5	*Actinomma* sp. 1	
6	*Amphirrhopalum* sp.	
7	*Anomalocantha dentata*	Nigrini & Moore (1979; pl. 4, fig. 4)
8	*Anthocyrtidium ehrenbergi*	Fig. 21F, J; Nigrini & Lombari (1984; pl. 27, figs 1-2)
9	*Arachnocorallium* sp.	Riedel *et al.* (1985; pl. 3, figs 13a-c)
10	*Hymeniastrum* sp.	Riedel *et al.* (1985; pl. 2, fig. 2a)
11	*Botryostrobus auritus/australis*	Fig. 21K, N; Riedel *et al.* (1985; pl. 5, fig. 7)
12	*Carpocanarium papillosum*	Nigrini & Moore (1979; pl. 21, fig. 3)
13	*Carpocanistrum* sp.	Fig. 21O, S; Riedel *et al.* (1985; pl. 5, figs 2-3)
14	*Cenosphaera cristata?*	Nigrini & Moore (1979; pl. 4, figs 2a-b)
15	*Cenosphaera* sp. 2	Fig. 20B, E; Nigrini & Moore (1979; pl. 4, fig. 3b)
16	*Ceratocyrtis* sp.	Riedel *et al.* (1985; pl. 3, fig. 14b)
17	*Cornutella profunda*	Fig. 21G, I; Nigrini & Lombari (1984; pl. 22, fig. 1)
18	*Cyrtocapsella cylindroides*	Nigrini & Lombari (1984; pl. 23, fig. 2)
19	*Didymocyrtis* sp.	Fig. 21G, J; Nigrini & Moore (1979; pl. 4, fig. 3b)
20	*Euchitonia furcata*	Nigrini & Lombari (1984; pl. 8, fig. 1)
21	*Eucyrtidium cienkowskii*	Nigrini & Lombari (1984; pl. 23, fig. 6)
22	*Eucyrtidium hexagonatum*	Nigrini & Lombari (1984; pl. 23, fig. 8)
23	*Eucyrtidium* sp. cf. *E. holospira*	Petrushevskaya (1981; fig. 295)
24	*Eucyrtidium punctatum*	Fig. 22R, W; Riedel *et al.* (1974, pl. 62, Fig. 6)
25	*Heliodiscus asteriscus*	Nigrini & Lombari (1984; pl. 5, Fig. 4)
26	*Heliodiscus echiniscus*	Riedel *et al.* (1974, pl. 56, Fig. 5)
27	*Hexacontium arachnoidale*	Fig. 20D; Hollande & Enjumet (1960, pl. LIII, Fig. 1)
28	*Hexacontium pachydermum* (big)	Fig. 20F; Riedel *et al.* (1985; pl. 1, Fig. 6a)
29	*Hexacontium pachydermum* (small)	Fig. 20C; Riedel *et al.* (1985; pl. 1, Fig. 6c)
30	*Hexacontium* sp.	
31	*Hexapyle* sp.	
32	*Hymeniastrum* sp.	Fig. 20I; Riedel *et al.* (1985; pl. 2, Fig. 2b)
33	*Larcoid* sp. 1 (spiral)	
34	*Larcoid* sp. 2 (small)	
35	Larcoidea sp.	Fig. 20K, L
36	*Larcopyle buetschlii*	Nigrini & Moore (1979; pl. 17, figs 1a-b)
37	*Larcopyle* sp.	Riedel *et al.* (1985; pl. 2, figs 11a-b)
38	*Larcospira quadrangula*	Nigrini & Lombari (1984; pl. 13, Fig. 3)
39	*Lipmanella* sp.	Riedel *et al.* (1985; pl. 4, Fig. 9)
40	*Litharachnium* sp.	Fig. 22M; Riedel *et al.* (1985; pl. 4, fig.11)
41	*Lithomelissa* sp. cf. *L. setosa*	Fig. 22F-L; Riedel *et al.* (1985; pl. 3, fig.15c)
42	*Lithomitra arachnea*	Riedel *et al.* (1985; pl. 5, Fig. 8b)
43	*Lithomitra* sp. cf. *L. lineata*	Fig. 21H, L, M; Riedel *et al.* (1985; pl. 5, Fig. 8a)
44	*Lophophaena buetschlii*	Petrushevskaya (1971, Fig. 58 I-X)
45	*Lophophaena* sp.	Fig. 21O, S
46	*Tetrapyle octacantha*	Nigrini & Lombari (1984; pl. 12, Fig. 3)
47	*Phormostichoartus corbula*	Nigrini & Lombari (1984; pl. 31, Fig. 4)
48	*Phorticium polycladum*	Nigrini & Lombari (1984; pl. 12, Fig. 1)
49	*Porodiscus* sp.	Riedel *et al.* (1985; pl. 2, figs 3-4)
50	*Pterocanium* sp.	Riedel *et al.* (1974, pl. 60, figs 4-6)
51	*Spongaster berminghami*	Nigrini & Lombari (1984; pl. 9, Fig. 1)
52	*Spongotrochus glacialis*	Nigrini & Lombari (1984; pl. 11, Fig. 2)

	Taxa	References for illustrations
53	*Spongotrochus resurgens osculosa*	Gig. 20A; Nigrini & Lombari (1984; pl. 11, Fig. 1)
54	*Hexalonche* sp.	
55	*Stichocorys delmontensis*	Fig. 21A-E; Nigrini & Lombari (1984; pl. 25, Fig. 4)
56	*Stichocorys delmontensis* (dwarf)	
57	*Stichocorys delmontensis* (thick)	
58	*Stichocorys delmontensis* (thin)	
59	*Stichocorys peregrina*?	Nigrini & Lombari (1984; pl. 25, Fig. 6)
60	*Stylochlamydium venustum*	Fig. 20M; Nigrini & Lombari (1984; pl. 11, Fig. 3)
61	*Stylodictya aculeata*	Jørgensen (1905, pl X, Fig. 41)
62	*Stylodictya tenuispina*	Bjørklund (1976, pl. 4, Fig. 5)
63	*Stylodictya validispina*	Bjørklund (1976, pl. 4, fig. 4)
64	*Stylosphaera angelina*	Riedel *et al.* (1974, pl. 56, fig. 2)
65	*Thecosphaera grecoi*	Fig. 20H; Riedel *et al.* (1974, pl. 56, fig. 3)
66	*Theocapsa? cretica*	Fig. 22T-V Riedel *et al.* (1985; pl. 4, fig. 15)
67	Trissocyclidae sp.	Fig. 21T-Y
68	*Zygocircus productus*	Nigrini & Lombari (1984; pl. 15, figs 1-2)

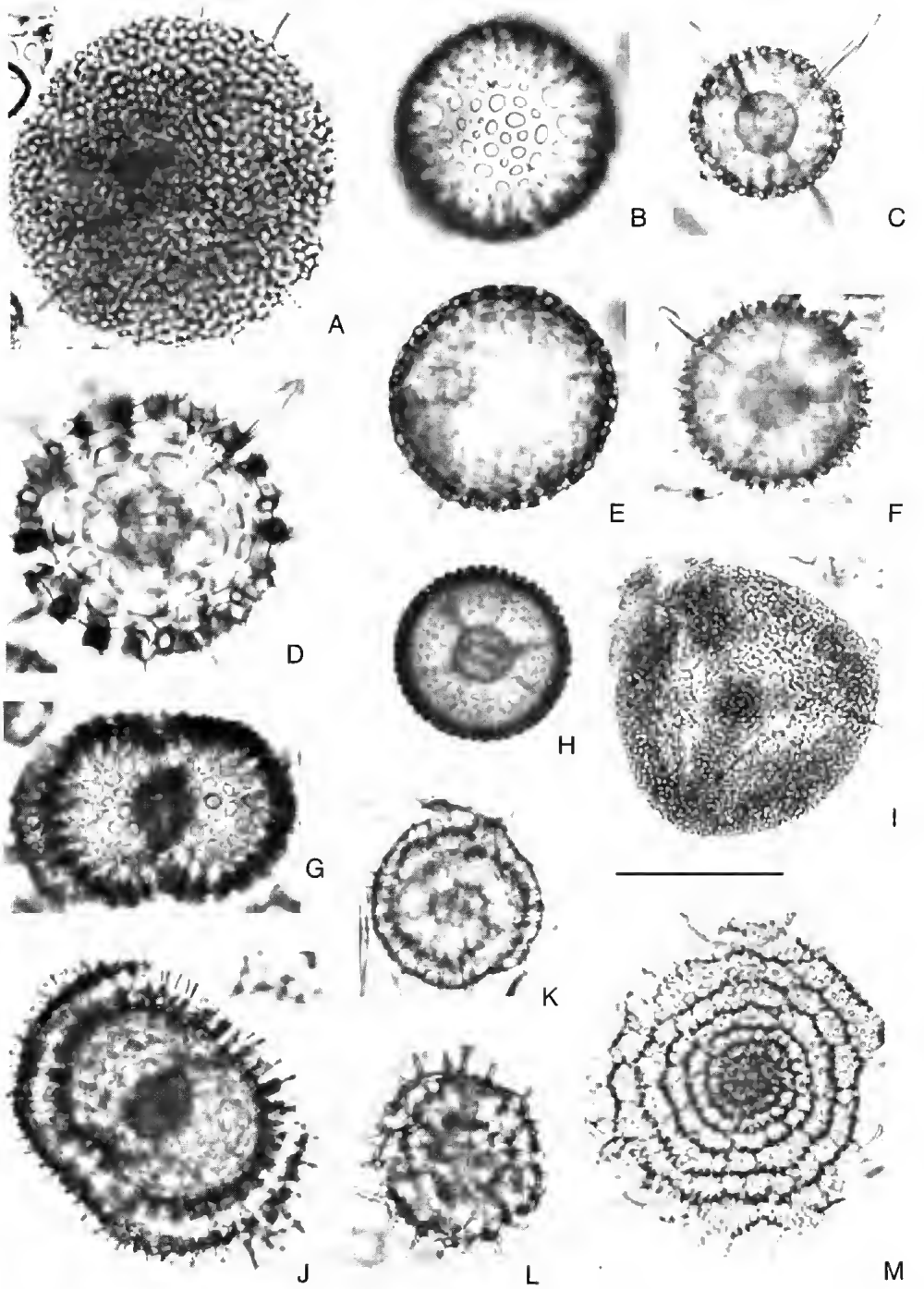

FIG. 20. — **A**, *Spongotrochus glacialis/osculosa* (D26.11); **B**, **E**, *Cenosphaera* sp. 2 (D20.2); **C**, *Hexacontium pachydermum* (small) (D20.2); **D**, *Hexacontium arachnoidale* (D20.2); **F**, *Hexacontium pachydermum* (big) (D31.2); **G**, **J**, *Didymocyrtis* sp. (D26.11); **H**, *Thecosphaera grecoi* (D27.2); **I**, *Hymeniastrum* sp. **K**, **L**, Larcoidea sp. (D27.2); **M**, *Stylochlamydium venustum* (D27.2). Scale bar: 100 µm.

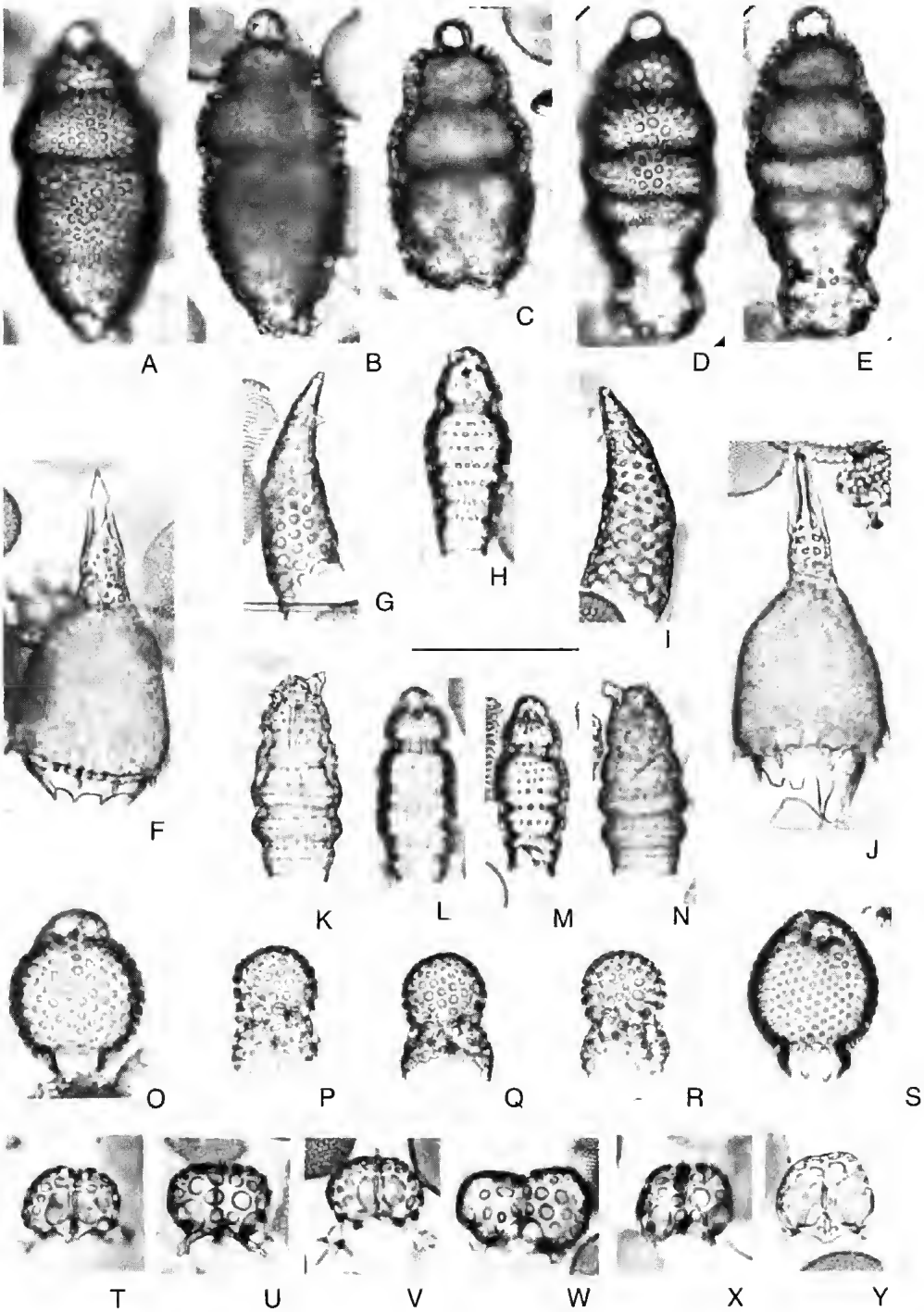

FIG. 21. — **A-E**, *Stichocorys delmontensis* (D17.1); **F**, **J**, *Anthocyrtidium ehrenbergi* (D20.2); **G**, **I**, *Cornutella profunda* (D17.1); **H**, **L**, **M**, *Lithomitra lineata* (D4.9); **K**, **N**, *Botryostrobus auritus/australis* (D21.22); **O**, **S**, *Carpocanistrum* sp. (D26.11); **P-R**, *Lophophaena* sp. (D26.11); **T-Y**, Trissocyclidae sp. (D17.1). Scale bar: 100 µm.

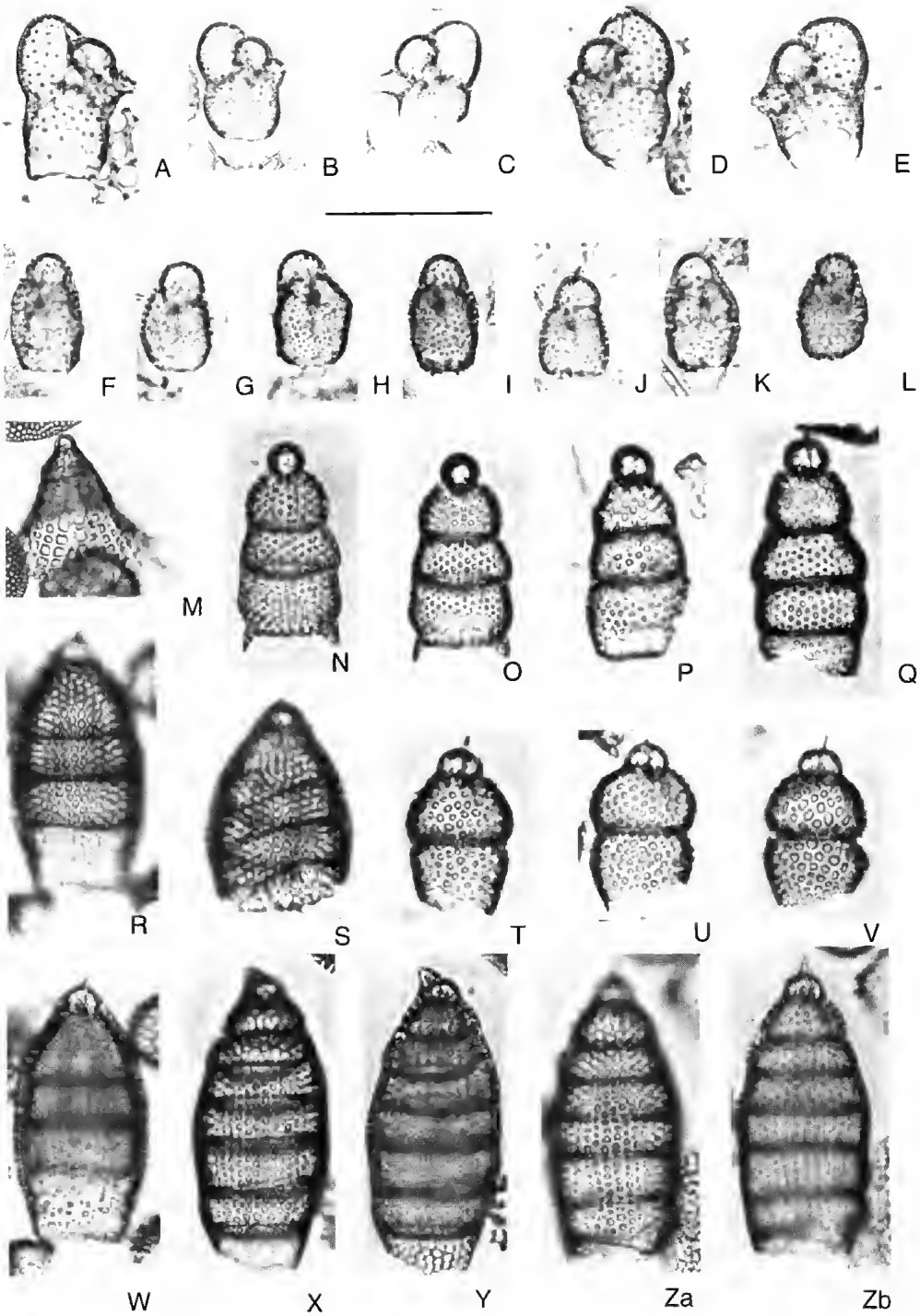

FIG. 22. — **A-E**, *Botryopyle* sp. (D26.11); **F-L**, *Lithomelissa* sp. cf. *L. setosa* (D28.0); **M**, *Litharachnium* sp. (D26.11); **N-Q**, *Stichocorys delmontensis* (D26.11); **R, W**, *Eucyrtidium punctatum* (D26.11), same specimen; **S**, *Eucyrtidium* sp. cf. *E. holospira* (D26.11); **T-V**, *Theocapsa* ? *cretica*; **X-Zb**, *Eucyrtidium* sp. (D26.11). Scale bar: 100 µm.

TABLE 2. — Estimated age above section base, radiolarian flux, number of radiolarians per gram $CaCO_3$-free sediment, number of nassellarians, spumellarians and radiolarians per gram bulk sediment, Spumellaria/Nassellaria ratio, $CaCO_3$ and TOC content for each of the samples collected during the 1995 field-trip (one sample for each lithology)

Sample Code	Years above Section base	Flux in ky/cm²	Rads gcf	Number of Spum/g	Number of Nass/g	Number of Rads/g	S/N ratio	Percent $CaCO_3$	Percent TOC
D 36	757000	23698	82123	28553	12437	40990	2.30	50.09	0.100
D 35	736000	1351	1447	173	1038	1211	0.17	16.29	0.095
D 34	715000	8397	6595	810	5263	6073	0.15	7.92	0.000
D 33	694000	108560	269415	107042	33627	140669	3.18	47.79	0.116
D 32	673000	27978	37831	14613	5874	20487	2.49	45.85	0.139
D 31	652000	48261	55561	23518	20356	43874	1.16	21.04	0.096
D 30	631000	3261	4787	1786	2273	4058	0.79	15.22	0.144
D 29	610000	8967	8240	2141	4587	6728	0.47	18.35	0.158
D 28	589000	61163	73836	19427	14417	33845	1.35	54.16	0.131
D 27	567000	24777	41790	7242	5850	13092	1.24	68.67	0.070
D 26	546000	303644	258157	95126	74368	169495	1.28	34.34	0.129
D 21	525000	57511	71345	14480	20916	35396	0.69	50.39	0.174
S 21	504000	3217	2121	437	1310	1747	0.33	17.64	0.133
D 20	399000	46565	45089	12654	10328	22982	1.23	49.03	0.117
S 20	399000	139	155	98	0	98	>1	36.62	0.106
D 19	378000	101764	65397	16756	28966	45722	0.58	30.09	0.120
S 19	378000	0	0	0	0	0	–	17.76	0.069
D 18	357000	31793	64398	20134	32215	52349	0.63	18.71	0.115
S 18	357000	15897	34789	9099	12408	21507	0.73	38.18	0.139
D 17	336000	63761	54258	14449	29106	43555	0.50	19.73	0.113
S 17	336000	0	0	0	0	0	–	33.52	0.118
D 16	315000	40402	118495	20516	39013	59529	0.53	49.76	0.129
S 16	315000	0	0	0	0	0	–	23.73	0.063
D 15	294000	110185	109436	22199	46934	69133	0.47	36.83	0.091
S 15	294000	505	500	312	0	312	>1	37.68	0.139
S 14	273000	0	0	0	0	0	–	40.49	0.121
D 13	273000	62848	76710	21456	24369	45825	0.88	40.26	0.149
S 13	252000	1598	2033	1463	0	1463	–	28.02	0.148
D 12	231000	39217	48788	17328	13017	30345	1.33	37.80	0.144
S 12	231000	0	0	0	0	0	–	24.38	0.115
D 11	210000	54022	43391	7658	24324	31982	0.31	26.29	0.165
S 11	210000	77799	55215	26947	16105	43053	1.67	22.03	0.167
D 10	189000	41511	35230	14907	12836	27743	1.16	21.25	0.150
S 10	189000	0	0	0	0	0	–	16.07	0.112
D 9	168000	117065	53363	21005	19977	40982	1.05	23.20	0.166
S 9	168000	0	0	0	0	0	–	25.59	0.110
D 8	147000	52728	33096	15088	12665	27753	1.19	16.14	0.173
S 8	147000	0	0	0	0	0	–	13.67	0.150
D 7	126000	124783	50841	15618	27358	42977	0.57	15.47	0.144
S 7	126000	609	284	115	115	230	1.00	18.82	0.172
D 6	105000	109467	44065	18243	17761	36004	1.03	18.29	0.105
S 6	105000	293	173	0	122	122	<1	29.35	0.178
D 5	84000	89435	66214	17864	18447	36311	0.97	45.16	0.111
S 5	84000	478	306	117	117	234	1.00	23.64	0.154
D 4	63000	45446	34871	13299	10000	23299	1.33	33.19	0.118
S 4	63000	0	0	0	0	0	–	30.59	0.070
D 3	42000	0	0	0	0	0	–	34.48	0.083
D 2	21000	0	0	0	0	0	–	28.94	0.058
S 2	21000	190	169	0	120	120	<1	29.20	0.166

TABLE 3. — Number of nassellarians, spumellarians and radiolarians per gram bulk sediment and S/N ratio for each of the samples of diatomite D7. Cycle 7 is 84.9 cm thick, with the diatomite and claystone lithologies making up 46.9 and 38 cm, respectively.

Sample Number	Distance from base (cm)	(%)	Years from base cycle	section	Number of Spum/g	Nass/g	Rads/g	Spum/Nass ratio
F97- Dia 7.28	84.9	1.000	21000	147000	13686	21773	35459	0.63
F97- Dia 7.27	82.6	0.973	20431	146431	12306	21632	33938	0.57
F97- Dia 7.26	81.2	0.956	20085	146085	11261	15878	27140	0.71
F97- Dia 7.25	79.7	0.939	19714	145714	13445	20483	33929	0.66
F97- Dia 7.24	78.2	0.921	19343	145343	17670	24537	42207	0.72
F97- Dia 7.23	76.0	0.895	18799	144799	19434	29434	48868	0.66
F97- Dia 7.22	75.1	0.885	18576	144576	14175	18986	33162	0.75
F97- Dia 7.21	73.0	0.860	18057	144057	14725	29126	43851	0.51
F97- Dia 7.20	72.1	0.849	17834	143834	15123	30435	45558	0.50
F97- Dia 7.19	70.3	0.828	17389	143389	15570	26023	41594	0.60
F97- Dia 7.18	68.0	0.801	16820	142820	18945	34892	53837	0.54
F97- Dia 7.17	66.5	0.783	16449	142449	17131	27888	45020	0.61
F97- Dia 7.16	64.8	0.763	16028	142028	27557	33239	60795	0.83
F97- Dia 7.15	63.1	0.743	15608	141608	25047	36622	61670	0.68
F97- Dia 7.14	61.4	0.723	15187	141187	16997	23597	40594	0.72
F97- Dia 7.13	60.4	0.711	14940	140940	24356	33262	57618	0.73
F97- Dia 7.12	59.0	0.695	14594	140594	29529	37059	66588	0.80
F97- Dia 7.11	57.5	0.677	14223	140223	29266	41253	70518	0.71
F97- Dia 7.10	56.0	0.660	13852	139852	21444	34914	56358	0.61
F97- Dia 7.9	54.4	0.641	13456	139456	14881	25794	40675	0.58
F97- Dia 7.8	52.7	0.621	13035	139035	18472	35694	54167	0.52
F97- Dia 7.7	50.2	0.591	12417	138417	17090	39594	56684	0.43
F97- Dia 7.6	48.3	0.569	11947	137947	25338	52196	77534	0.49
F97- Dia 7.5	46.5	0.548	11502	137502	30425	33884	64308	0.90
F97- Dia 7.4	44.8	0.528	11081	137081	28993	24029	53022	1.21
F97- Dia 7.3	43.0	0.506	10636	136636	72072	45195	117267	1.59
F97- Dia 7.2	41.3	0.486	10216	136216	38832	60745	99577	0.64
F97- Dia 7.1	39.6	0.466	9795	135795	49799	36419	86217	1.37

TABLE 4. — Number of nassellarians, spumellarians and radiolarians per gram bulk sediment and S/N ratio for each of the samples of diatomite D21. Cycle 21 is 74 cm thick, with the diatomite and claystone lithologies making up 64 and 10 cm, respectively.

Sample Number	Distance from base (cm)	(%)	Years from base cycle	section	Number of Spum/g	Nass/g	Rads/g	Spum/Nass ratio
F95- Dia 21.0	74.0	1.000	21000	420000	16311	26866	43177	0.61
F95- Dia 21.1	73.0	0.986	20716	419716	15772	24497	40268	0.64
F95- Dia 21.2	72.0	0.973	20432	419432	15846	24311	40157	0.65
F95- Dia 21.3	71.0	0.959	20149	419149	21343	27655	48998	0.77
F95- Dia 21.4	70.0	0.946	19865	418865	22346	17318	39665	1.29
F95- Dia 21.5	69.0	0.932	19581	418581	15962	21009	36972	0.76
F95- Dia 21.6	68.0	0.919	19297	418297	13426	23495	36921	0.57
F95- Dia 21.7	67.0	0.905	19014	418014	16762	19810	36571	0.85
F95- Dia 21.8	66.0	0.892	18730	417730	11816	24378	36194	0.48
F95- Dia 21.9	65.0	0.878	18446	417446	18607	16895	35502	1.10
F95- Dia 21.10	64.0	0.865	18162	417162	15256	22692	37949	0.67
F95- Dia 21.11	63.0	0.851	17878	416878	16951	19723	36674	0.86
F95- Dia 21.12	62.0	0.838	17595	416595	10808	17795	28603	0.61
F95- Dia 21.13	61.0	0.824	17311	416311	17584	21292	38876	0.83
F95- Dia 21.14	59.5	0.804	16885	415885	10758	23182	33939	0.46
F95- Dia 21.15	58.0	0.784	16459	415459	11364	23529	34893	0.48
F95- Dia 21.16	56.5	0.764	16034	415034	16412	23282	39695	0.70
F95- Dia 21.17	55.0	0.743	15608	414608	11944	25833	37778	0.46
F95- Dia 21.18	53.5	0.723	15182	414182	10976	23018	33994	0.48
F95- Dia 21.19	52.0	0.703	14757	413757	8411	19938	28349	0.42
F95- Dia 21.20	50.5	0.682	14331	413331	12791	33866	46657	0.38
F95- Dia 21.21	49.0	0.662	13905	412905	12431	27901	40331	0.45
F95- Dia 21.22	47.5	0.642	13480	412480	14480	20916	35396	0.69
F95- Dia 21.23	46.0	0.622	13054	412054	10853	21318	32171	0.51
F95- Dia 21.24	44.5	0.601	12628	411628	11887	22304	34191	0.53
F95- Dia 21.25	43.0	0.581	12203	411203	15833	27024	42857	0.59
F95- Dia 21.26	41.5	0.561	11777	410777	13523	13295	26818	1.02
F95- Dia 21.27	40.0	0.541	11351	410351	12529	14988	27518	0.84
F95- Dia 21.28	38.5	0.520	10926	409926	10684	13355	24038	0.80
F95- Dia 21.29	37.0	0.500	10500	409500	10462	14402	24864	0.73
F95- Dia 21.30	35.5	0.480	10074	409074	14321	18272	32593	0.78
F95- Dia 21.31	34.0	0.459	9649	408649	13921	16241	30162	0.86
F95- Dia 21.32	32.5	0.439	9223	408223	13079	16898	29977	0.77
F95- Dia 21.33	31.0	0.419	8797	407797	13270	14692	27962	0.90
F95- Dia 21.34	29.5	0.399	8372	407372	16085	22569	38653	0.71
F95- Dia 21.35	28.0	0.378	7946	406946	15179	13616	28795	1.11
F95- Dia 21.36	26.5	0.358	7520	406520	19036	21687	40723	0.88
F95- Dia 21.37	25.0	0.338	7095	406095	15556	14198	29753	1.10
F95- Dia 21.38	23.5	0.318	6669	405669	18750	17428	36178	1.08
F95- Dia 21.39	22.0	0.297	6243	405243	18810	19881	38690	0.95
F95- Dia 21.40	20.5	0.277	5818	404818	35455	21932	57386	1.62
F95- Dia 21.41	19.0	0.257	5392	404392	30383	26077	56459	1.17
F95- Dia 21.42	17.5	0.236	4966	403966	34852	23517	58369	1.48
F95- Dia 21.43	16.0	0.216	4541	403541	34709	14071	48780	2.47
F95- Dia 21.44	14.5	0.196	4115	403115	46758	29371	76130	1.59
F95- Dia 21.45	13.0	0.176	3689	402689	44615	41868	86484	1.07
F95- Dia 21.46	11.5	0.155	3264	402264	48364	42545	90909	1.14
F95- Dia 21.47	10.0	0.135	2838	401838	41189	72687	113877	0.57

TABLE 5. — Number of nassellarians, spumellarians and radiolarians per gram bulk sediment and S/N ratio for each of the samples of diatomite D28. Cycle 28 is 95.7 cm thick, with the diatomite and claystone lithologies making up 49.7 and 46 cm, respectively.

Sample Number	Distance from base (cm)	(%)	Years from base cycle	section	Number of Spum/g	Nass/g	Rads/g	Spum/Nass ratio
F97- Dia 28.36	95.7	1.000	21000	588000	6911	256	7167	27.00
F97- Dia 28.35	94.2	0.984	20671	587671	5876	100	5976	59.00
F97- Dia 28.34	92.5	0.967	20298	587298	5753	105	5858	55.00
F97- Dia 28.33	91.1	0.952	19991	586991	3035	160	3195	19.00
F97- Dia 28.32	89.9	0.939	19727	586727	4006	148	4154	27.00
F97- Dia 28.31	88.8	0.928	19486	586486	3482	418	3900	8.33
F97- Dia 28.30	87.6	0.915	19223	586223	5307	83	5390	64.00
F97- Dia 28.29	85.5	0.893	18762	585762	3765	235	4000	16.00
F97- Dia 28.28	84.0	0.878	18433	585433	3282	290	3571	11.33
F97- Dia 28.27	82.3	0.860	18060	585060	4340	362	4702	12.00
F97- Dia 28.26	80.6	0.842	17687	584687	3623	580	4203	6.25
F97- Dia 28.25	79.4	0.830	17423	584423	4364	285	4649	15.33
F97- Dia 28.24	77.7	0.812	17050	584050	3583	489	4072	7.33
F97- Dia 28.23	76.7	0.801	16831	583831	2490	1452	3942	1.71
F97- Dia 28.22	75.7	0.791	16611	583611	5724	818	6542	7.00
F97- Dia 28.21	74.3	0.776	16304	583304	5889	1501	7390	3.92
F97- Dia 28.20	73.0	0.763	16019	583019	8918	2778	11696	3.21
F97- Dia 28.19B	72.0	0.752	15799	582799	3101	1163	4264	2.67
F97- Dia 28.19A	70.8	0.740	15536	582536	6393	2295	8689	2.79
F97- Dia 28.18	69.8	0.729	15317	582317	5938	3438	9375	1.73
F97- Dia 28.17	68.7	0.718	15075	582075	7943	3010	10953	2.64
F97- Dia 28.16	67.4	0.704	14790	581790	7177	3589	10766	2.00
F97- Dia 28.15	66.3	0.693	14549	581549	6377	3050	9427	2.09
F97- Dia 28.14	64.9	0.678	14241	581241	8701	3016	11717	2.88
F97- Dia 28.13	63.7	0.666	13978	580978	12808	4803	17611	2.67
F97- Dia 28.12	62.5	0.653	13715	580715	19118	5042	24160	3.79
F97- Dia 28.11	61.5	0.643	13495	580495	21261	6944	28205	3.06
F97- Dia 28.10	60.4	0.631	13254	580254	18448	4580	23028	4.03
F97- Dia 28.9	58.5	0.611	12837	579837	17108	11153	28261	1.53
F97- Dia 28.8	57.2	0.598	12552	579552	18689	8611	27299	2.17
F97- Dia 28.7	55.9	0.584	12266	579266	33293	15865	49159	2.10
F97- Dia 28.6	54.7	0.572	12003	579003	36830	18192	55022	2.02
F97- Dia 28.5	53.3	0.557	11696	578696	27660	13032	40691	2.12
F97- Dia 28.4	52.2	0.545	11455	578455	41333	10917	52250	3.79
F97- Dia 28.3	50.5	0.528	11082	578082	42285	12725	55010	3.32
F97- Dia 28.2	49.1	0.513	10774	577774	35327	8323	43650	4.24
F97- Dia 28.1	47.1	0.492	10335	577335	41444	10444	51889	3.97

TABLE 6. — Varimax Factor Components Matrix (Samples *vs* Factors).

Samples	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
D36	0.082	0.724	0.078	-0.016	0.418	0.398	0.049	0.059	0.074
D35	0.007	0.149	0.009	-0.011	-0.003	0.904	-0.003	-0.011	-0.004
D34	0.858	0.175	0.092	-0.011	-0.079	-0.034	-0.001	0.425	-0.036
D33	0.043	0.423	0.048	-0.013	0.883	-0.021	0.092	-0.035	-0.003
D32	0.089	0.842	0.092	-0.029	0.489	0.044	0.091	0.042	0.093
D31	0.505	0.785	0.134	-0.025	0.223	0.048	0.021	-0.155	0.157
D30	0.111	0.894	0.108	0.247	-0.140	0.109	0.001	0.131	0.033
D29	0.115	0.863	0.043	-0.052	-0.113	-0.113	0.005	0.403	-0.010
D28	0.207	0.672	0.032	-0.062	0.024	-0.229	0.026	-0.281	-0.233
D27	0.122	0.901	0.124	0.003	-0.086	0.247	0.043	-0.094	0.031
D26	0.158	0.793	0.063	0.274	0.271	0.050	0.053	0.427	-0.011
D21	0.623	0.255	0.066	-0.011	-0.043	0.018	0.083	-0.003	0.708
S21	0.008	0.074	0.010	-0.001	0.086	0.005	0.993	0.003	0.034
D20	0.133	0.832	0.121	-0.026	0.263	0.052	0.048	-0.419	0.035
D19	0.976	0.141	0.120	-0.007	-0.013	0.000	0.010	-0.084	-0.073
D18	0.981	0.036	0.124	0.005	-0.036	0.045	0.009	-0.072	-0.003
S18	0.964	0.099	0.133	0.004	0.024	0.043	0.046	-0.109	-0.016
D17	0.958	0.197	0.138	-0.007	0.040	-0.001	0.027	-0.115	-0.035
D16	0.226	0.097	0.965	0.005	0.049	0.012	0.003	-0.070	0.009
S16	0.039	0.045	0.004	0.997	0.004	-0.017	0.000	0.000	-0.005
D15	0.695	-0.105	0.698	0.005	0.068	0.000	0.006	0.083	0.022
D13	0.978	0.059	0.108	0.011	0.118	0.037	0.016	0.070	0.079
S13	0.002	0.050	-0.005	0.997	0.004	-0.013	0.007	0.009	-0.006
D12	0.022	0.508	0.807	-0.005	-0.146	0.001	0.002	-0.087	0.139
D11	0.633	-0.109	0.755	0.004	0.024	-0.011	0.005	0.079	-0.026
S11	0.960	0.030	0.101	0.074	0.182	0.072	0.013	0.098	-0.002
D10	-0.069	0.115	0.982	0.000	0.109	-0.011	0.001	-0.021	0.018
D9	0.870	0.259	0.110	-0.010	0.010	0.013	0.011	-0.045	0.398
D8	0.121	0.800	0.065	-0.041	0.171	-0.112	0.019	-0.008	0.499
D7	0.984	0.112	0.122	-0.005	0.053	0.008	0.014	0.012	0.014
D6	0.934	0.226	0.116	-0.012	-0.043	-0.023	0.011	-0.115	0.200
D5	0.448	0.113	0.876	0.001	0.052	0.021	0.017	0.116	0.038
D4	0.876	0.206	0.321	-0.004	0.111	0.082	0.042	0.176	0.079
Var.	35,414	22,699	14,255	6,486	4,792	3,507	3,110	2,951	3,304
Cum. Var.	35,414	58,113	72,368	78,854	83,646	87,153	90,263	93,215	96,519

TABLE 7. — Scaled Varimax Factor Scores Matrix (Species *vs* Factor Scores). Absolute values of factor scores higher than one have been outlined.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
Anthocyrtidium ehrenbergi	-0.037	-0.048	0.000	0.011	-0.262	-0.014	3.111	0.018	0.065
Botryostrobus auritus/australis	0.183	0.264	-0.088	-0.058	-0.209	-0.488	-0.030	-0.300	3.360
Carpocanistrum sp.	0.000	0.060	0.005	-0.002	0.309	0.012	1.819	0.036	-0.073
Cenosphaera sp. 2	-0.005	-0.024	-0.012	-0.016	-0.164	1.939	-0.014	-0.197	-0.016
Didymocyrtis sp.	0.006	0.147	-0.031	3.595	0.013	-0.065	-0.010	0.020	-0.026
Larcoidea sp.	0.169	2.160	0.198	0.002	-0.220	1.116	0.046	0.705	0.465
Lithomelissa sp. cf. *L. setosa*	0.266	1.239	-0.136	-0.224	-0.599	-1.082	0.003	-0.767	-1.197
Lithomitra sp. cf. *L. lineata*	-0.376	-0.307	3.547	0.022	-0.010	-0.093	-0.009	0.176	0.034
Porodiscus sp.	0.088	1.282	0.151	-0.077	3.249	-0.164	0.059	-0.349	-0.027
Spongotrochus glacialis/osculosa	0.085	1.472	0.051	-0.102	-0.724	-0.602	-0.068	2.540	-0.168
Stichocorys delmontensis	3.535	-0.509	0.316	0.018	0.161	0.099	0.032	0.298	-0.087
Theocapsa ? cretica	-0.050	0.095	-0.014	-0.033	-0.046	2.484	-0.021	0.029	-0.095
Trissocyclidae sp.	0.459	1.591	0.473	0.018	-1.118	-0.002	-0.009	-2.256	-0.089

TABLE 8. — Factor component peaks (values higher than 0.400) used to establish the most important "radiolarian factor peaks" throughout the section. The peaks are coded as X.Y, where X represents the factor number and Y represents a reference number for the "factor peaks", arranged in an ascending order from base to top of the section.

Samples	Factor Peaks	Factor Component	Sapropel Age (Ma)	Diatomite Age (Ma)	Astro. ages	Tripoli Cycles
D36	2.12	0.724		6.183		
S36			6.194		6.132	T43
D35	6.1	0.904		6.204		
S35			6.215		6.145	T42
D34	1.16	0.858		6.225		
	8.4	0.425				
S34			6.236		6.164	T41
D33	2.11	0.423		6.246		
	5.2	0.883				
S33			6.257		6.184	T40
D32	2.10	0.842		6.267		
	5.1	0.489				
S32			6.278		6.205	T39
D31	1.15	0.505		6.288		
	2.9	0.785				
S31			6.299		6.226	T38
D30	2.8	0.894		6.309		
S30			6.320		6.257	T37
D29	2.7	0.863		6.331		
	8.3	0.403				
S29			6.342		6.278	T36
D28	2.6	0.672		6.352		
S28			6.363		6.299	T35
D27	2.5	0.901		6.373		
S27			6.384		6.320	T34
D26	2.4	0.793		6.394		
	8.2	0.427				
S26			6.405		6.342	T33
D26						
S25					*	T32
D24						
S24					6.373	T31
D23						
S23					6.393	T30
D22						
S22					6.413	T29
D21	1.14	0.623		6.499		
	9.2	0.708				
S21	7.1	0.993	6.510		6.432	T28
D20	2.3	0.832		6.520		
	8.1	-0.419				
S20			6.531		6.452	T27
D19	1.13	0.976		6.541		
S19			6.552		6.470	T26
D18	1.12	0.981		6.562		
S18	1.11	0.964	6.572		6.490	T25
D17	1.10	0.958		6.583		
S17			6.594		6.509	T24
D16	3.6	0.965		6.604		
S16	4.2	0.997	6.614		6.524	T23

Samples	Factor Peaks	Factor Component	Sapropel Age (Ma)	Diatomite Age (Ma)	Astro. ages	Tripoli Cycles
D15	1.9	0.695		6.625		
	3.5	0.698				
S15			6.636		6.544	T22
D14						
S14					6.563	T21
D13	1.8	0.978		6.667		
S13	4.1	0.997	6.678		6.585	T20
D12	2.2	0.508		6.688		
	3.4	0.807				
S12			6.699		6.606	T19
D11	1.7	0.633		6.709		
	3.3	0.755				
S11	1.6	0.960	6.719		6.635	T18
D10	3.2	0.982		6.730		
S10			6.741		6.657	T17
D9	1.5	0.870		6.751		
S9			6.762		6.678	T16
D8	2.1	0.800		6.772		
	9.1	0.499				
S8			6.783		6.699	T15
D7	1.4	0.984		6.793		
S7			6.804		6.721	T14
D6	1.3	0.934		6.814		
S6			6.825		6.752	T13
D5	1.2	0.448		6.835		
	3.1	0.876				
S5			6.846		6.771	T12
D4	1.1	0.876		6.856		
S4			6.867		6.792	T11
D3				6.877		
S3			6.888		6.810	T10
D2				6.898		
S2			6.909		6.829	T9
D1				6.919		
S1			6.930		6.847	T8

Taxonomic study of Ordovician (Llanvirn-Caradoc) Radiolaria from the Southern Uplands (Scotland, U.K.)

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ABSTRACT

Over 100 years ago, Hinde (1890a, b) described Radiolaria in thin sections from Ordovician cherts of the Southern Uplands of Scotland and established for the first time the presence of the group in the Early Palaeozoic. Radiolarians from the Southern Uplands have now been successfully extracted by hydrofluoric acid leaching and the systematic palaeontology of some of the yielded morphotypes is discussed herein. The studied fauna come from two outcrops of radiolarites: one at upper Hawkwood Burn and the other north-west of the village of Crawford. Amongst the radiolarians extracted from the latter outcrop, the genera *Inanibigutta* and *Protoceratoikiscum* are common. The presence of the species *Inanibigutta diffusa* (Hinde), *Inanibigutta* (?) *minuta* Wang and *Inanibigutta* sp. cf. *I. verrucula* (Nazarov) allows the correlation of the Crawford fauna with the *Haplentactinia juncta-Inanigutta unica* assemblage in Nazarov's (1988) biozonation, of upper Llanvirn (Llandeilian)-Caradoc age, and with the assemblage documented by Wang (1993) in China, of earliest Caradoc age.

KEY WORDS
Radiolaria,
Ordovician,
Llanvirn,
Caradoc,
Southern Uplands,
Scotland,
United Kingdom,
Iapetus Ocean,
Caledonides,
radiolarian chert.

RÉSUMÉ

Étude taxonomique des radiolaires ordoviciens (Llanvirnien-Caradocien) de Southern Uplands (Écosse, R.U.).

Des radiolaires ordoviciens ont été extraits à l'acide fluorhydrique des radiolarites de l'unité structurale des Southern Uplands en Écosse. Étudiés en lame-mince il y a plus d'un siècle (Hinde 1890a, b) ceux-ci ont servi comme témoin de la présence certaine de ce groupe dans le Paléozoïque inférieur. La faune ici étudiée vient de deux affleurements: l'un des radiolarites rouges brunâtres à Hawkwood Burn, l'autre des radiolarites grises qui affleurent au nord-ouest du village de Crawford. La paléontologie systématique de certaines formes intéressantes est ici discutée. Les genres *Inanibigutta* et *Protoceratoikiscum* sont communs parmi les radiolaires extraits des radiolarites de Crawford. La présence des espèces *Inanibigutta diffusa* (Hinde), *Inanibigutta* (?) *minuta* Wang et *Inanibigutta* sp. cf. *I. verrucula* (Nazarov) permet la corrélation de la faune de Crawford avec l'association *Haplentactinia juncta-Inanigutta unica* de la biozonation de Nazarov (1988), d'âge Llanvirnien supérieur (Llandeilien)-Caradocien, ainsi qu'avec l'association décrite par Wang (1993) en Chine, d'âge Caradocien basal.

MOTS CLÉS
Radiolaires, Ordovicien, Llanvirnien, Caradocien, Écosse, Royaume Uni, radiolarites, Océan Iapetus, Calédonides.

INTRODUCTION

Despite significant improvements in our understanding of Palaeozoic Radiolaria over the last 35 years, Early Palaeozoic assemblages are still poorly documented (Noble & Aitchison 1995). As a result, our knowledge of the early stages of evolution of this significant planktonic group remains limited. The oldest radiolarian fossils come from late Cambrian shallow-water limestones of China, from which one species has been recently described (Dong *et al.* 1997). Diversification markedly increased during the Ordovician and from the limited work that has been done so far, it is clear that radiolarian evolutionary change during this time was more rapid than previously believed (Renz 1990). The group has therefore the potential to become a valuable biostratigraphic tool for the yet poorly explored Early Palaeozoic interval, with an increasing number of easily identifiable, diagnostic taxa (Aitchison & Noble 1997; Aitchison 1998; Aitchison *et al.* 1998).

There are relatively few localities in the world where well-preserved Ordovician assemblages are known and most of them represent carbonate platform/slope environments (Fortey & Holdsworth 1971; Nazarov & Popov 1980; Webby & Blom 1986; Renz 1990; Wang 1993). Radiolaria of oceanic affinity are common, but less well preserved, in rocks of deep water origin such as radiolarites (ribbon radiolarian cherts with shaly intervals) which are often associated with remnants of oceanic crust in accretionary prisms of ancient subduction zones. They reflect the significant biogeochemical role that Radiolaria started to play in the oceans (i.e. the silica cycle) from the Early Palaeozoic.

The occurrence of radiolarians in cherts of the Southern Uplands terrane (Fig. 1) has been known for over a century. It was on material from this region that Hinde (1890a, b) first established the definite presence of Radiolaria in the Early Palaeozoic. Outcrops of radiolarian cherts were extensively discussed by Peach & Horne (1899), who were responsible for a major mapping compilation of the geology of Southern Scotland. Radiolaria from the Southern Uplands have also been reported by Nicholson (1889) and Smith (1900). The techniques available at

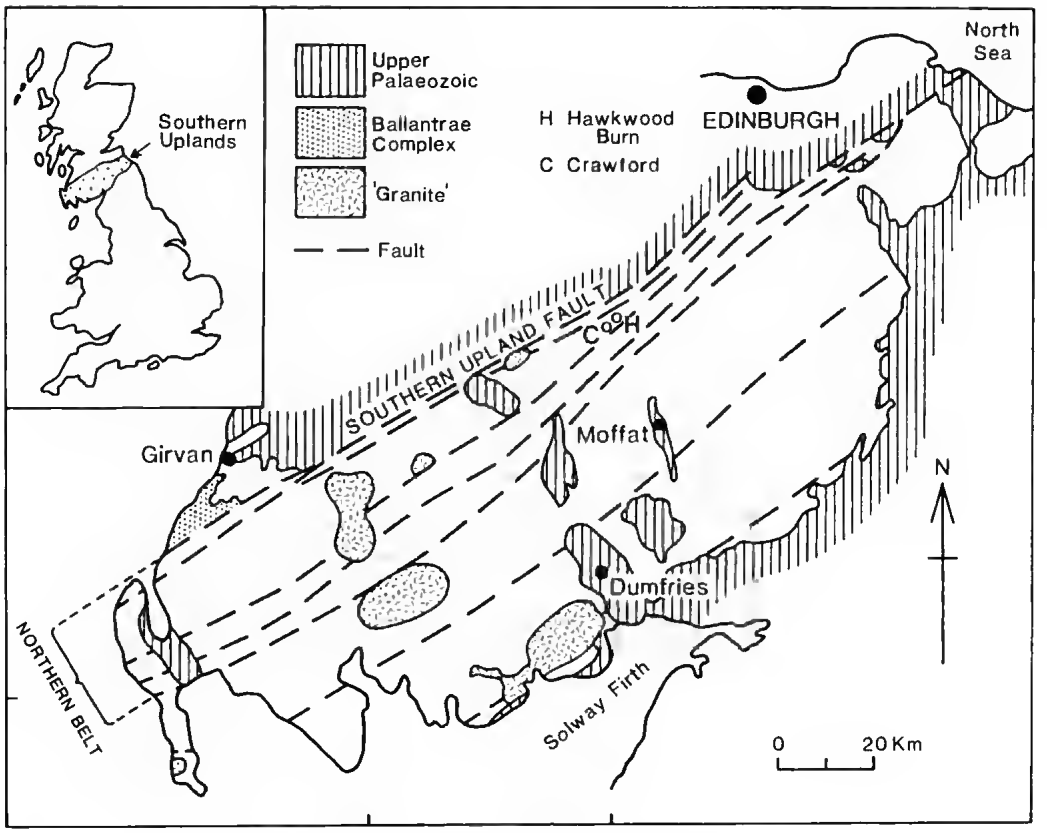

FIG. 1. — Geological outline of the Southern Uplands. Based on McAdam *et al.* (1993).

that time only allowed for study of Radiolaria in thin section, which provided very limited information on their morphology. This was naturally the case for the single previous taxonomic work of Radiolaria from the Southern Uplands (Hinde 1890b) in which 23 new species were described. Recognising the potential of radiolarian studies in the Southern Uplands, a number of radiolarian chert outcrops have already been examined and the results briefly reported (Danelian & Clarkson 1998). This paper focuses on the systematic study of some of the yielded morphotypes based on modern radiolarian taxonomy (e.g., Nazarov & Popov 1980; Nazarov 1988). It attempts to link matrix-free forms to the species described originally by Hinde and to gradually build a detailed and integrated picture of the radiolarian assemblages occuring in these historically important Scottish localities.

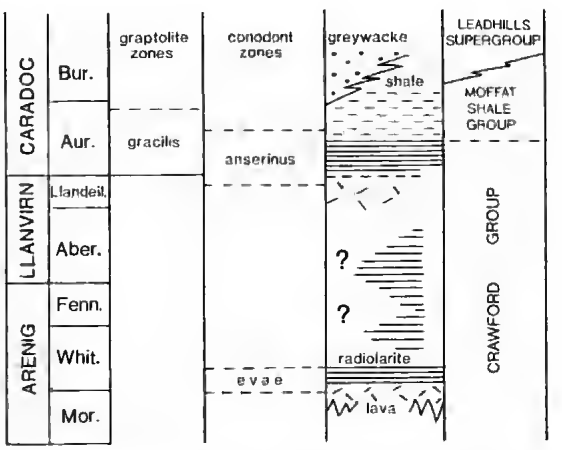

FIG. 2. — Simplified stratigraphy for the Lower-Middle Ordovician of the Southern Uplands, focusing on the Crawford Group. Lithostratigraphic terminology according to Floyd (1996). Chronostratigraphy and biostratigraphy from Fortey *et al.* (1995).

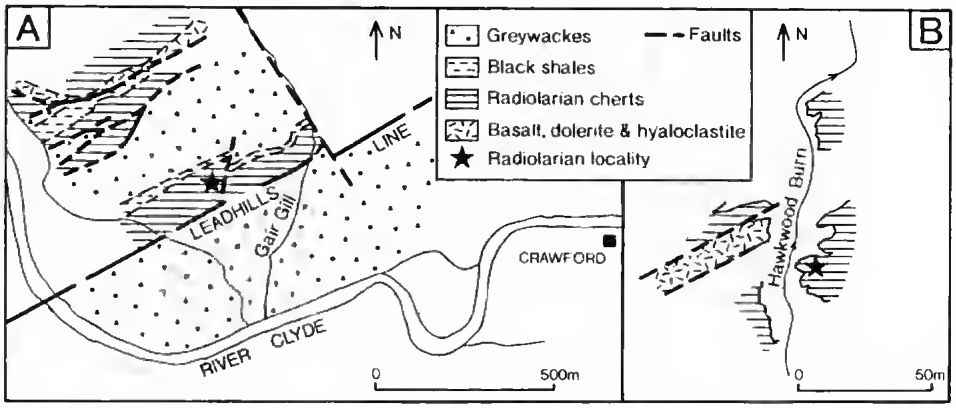

FIG. 3. — Geological map of the studied localities. **A**, north-west of the village of Crawford (after Leggett & Casey 1980); **B**, at Hawkwood Burn (after Clarkson *et al.* 1993).

STRATIGRAPHICAL FRAMEWORK

The Southern Uplands consist largely of Ordovician and Silurian sedimentary rocks of deep-water origin. The oldest rocks at the base of the succession are composed mainly of basaltic lavas, radiolarian cherts and siliceous mudstones. A formal lithostratigraphy for the Ordovician has recently been defined by Floyd (1996). The lavas and radiolarites are part of the Crawford Group of Arenig-Llanvirn age (*sensu* Fortey *et al.* 1995), although based on recent conodont evidence the Group probably extends into the Caradoc (Armstrong *et al.* 1990, 1996). The overlying graptolitic shales of the Moffat Shale Group (Caradoc-Llandovery) are in turn succeeded by the greywacke successions of the Leadhills Supergroup (Fig. 2).

Until recently, the various outcrops of radiolarian cherts in the Southern Uplands were considered as being part of a single continuous stratigraphical sequence, spanning the Arenig and Llanvirn, and overlain by the early Caradoc (*Nemagraptus gracilis* graptolite biozone) Moffat Shale Group (Leggett 1978, 1987). However Armstrong *et al.* (1996), after an extensive revision, suggested that radiolarian cherts could represent two distinct sedimentary events: one during the mid Arenig (*Oepikodus evae* conodont biozone), and one of latest Llanvirn to earliest Caradoc age (*Pygodus anserinus* conodont biozone).

BIOSTRATIGRAPHICAL DISCUSSION

The fauna discussed herein were extracted from two chert samples, one from an outcrop along the lower part of a trackside cutting, north-west of the village of Crawford (National Grid Reference NS 941 215; Figs 1, 3A) and the other from radiolarites cropping out at upper Hawkwood Burn (NS 972 248), a tributary of the Wandel Burn (Figs 1, 3B). Samples were processed with the laboratory technique of hydrofluoric acid (Dumitrica 1970; Pessagno & Newport 1972).

At Hawkwood Burn, the radiolarian cherts are of red-brownish colour and were recently described by Clarkson *et al.* (1993). From the base of these cherts a conodont faunule of late Llanvirn (Llandeilian)-earliest Caradoc age was reported (Armstrong *et al.* 1990, 1996). Although radiolarian preservation here does not allow any confident identification of established species, the fauna seem to be comparable to the *Haplentactinia juncta-Inanigutta unica* assemblage of Nazarov's biozonation (Llandeilian-Caradoc: Nazarov 1988; Nazarov & Ormiston 1993), which is consistent with the age given on the basis of conodonts.

In the second locality, near the village of Crawford, the radiolarites are mainly greenish-grey in colour. No biostratigraphic data other than that provided by the radiolarians exist for

the age of this outcrop. The presence of the genus *Protoceratoikiscum* is important because it suggests a Llanvirn-Caradoc interval (*sensu* Fortey *et al.* 1995) as a first approximation for the age of these cherts (Danelian & Clakson 1998). The presence of the species *Inanibigutta diffusa*, established herein (Fig. 4A-D), now allows the correlation of the Crawford fauna with the *Haplentactinia juncta-Inanigutta unica* assemblage of Nazarov's biozonation of late Llanvirn (Llandeilian)-Caradoc age. Moreover, the identification of *Inanibigutta* (?) *minuta* (Fig. 4F-G) and *Inanibigutta* sp. cf. *I. verrucula* (Fig. 4H) allows the correlation of the Crawford assemblage with the one documented by Wang (1993) from the Pingliang Formation, dated as of earliest Caradoc age (common interval between the *N. gracilis* and *P. anserinus* biozones).

SYSTEMATIC PALAEONTOLOGY

Subclass RADIOLARIA Müller, 1858
Superorder POLYCYSTINA Ehrenberg, 1838
emend. Riedel, 1967
Order SPUMELLARIA Ehrenberg, 1857
Family INANIGUTTIDAE
Nazarov & Ormiston, 1984

Genus *Inanibigutta* Nazarov, 1988

Inanibigutta Nazarov, 1988: 56. – Nazarov & Ormiston 1993: 35.

TYPE SPECIES. — *Entactinosphaera aksakensis* Nazarov, 1975.

Inanibigutta diffusa (Hinde, 1890b)
(Fig. 4A-D)

Stauroplegma diffusum Hinde, 1890b: 50, pl. 4, fig. 4.
Entactinosphaera ? diffusa (Hinde) – Nazarov & Popov 1980: 37, 38, text-fig. 16, pl. 2, fig. 4, pl. 13, fig. 8.
Inanibigutta diffusa (Hinde) – Nazarov 1988, fig. 31.

OCCURRENCE. — Middle Ordovician (Llandeilan to Lower Caradoc) Bestomakskaya Suite, Eastern Kazakhstan, southwestern foothills of the Chingiz Range, Chagan River (Nazarov & Popov 1980); Broughton Heights, Peebleshire, Southern Uplands (Hinde 1890b); grey radiolarites of the Crawford track, Southern Uplands, this study.

MEASUREMENTS (one specimen). — Diameter of the flattened part of the outer shell, 133-136 µm; diameter of the elongated part of the outer shell, 152-154 µm; length of main spines, 40-50 µm; diameter of inner shell, 63-66 µm.

DESCRIPTION
A nearly spherical outer shell bearing six radiating main spines positioned with hexagonal symmetry. The outer shell is perforated by circular to oval pores of various dimensions. The main spines are robust, rod-like, and gently tapering distally. They are almost half the length of the diameter of the outer shell. A number of needle-like secondary spines cover the surface of the outer shell. The inner shell is relatively small, perforated and linked to the outer shell through radial beams that continue as main spines outside the outer shell. Its position is eccentric in relation to the center of the outer shell (Fig. 4C-D).

REMARKS
The eccentric position of the inner shell was pointed out by Nazarov (*in* Nazarov & Popov 1980) and can be observed on the holotype illustrated by Hinde (1890b), which is obviously a section through an equatorial plan encompassing four spines. Only one specimen in our sample was identifiable with certainty. Nevertheless, several other naturally broken but incomplete specimens may belong to this species (Fig. 4E). The dimensions of our specimen correspond precisely to the ones measured by Hinde (1890b). However, Nazarov (*in* Nazarov & Popov 1980) accepted a larger variability of size for this species, especially as far as the length of spines is concerned. The latter author also mentioned that a spongiform texture was observed on the outer shell of some of his specimens from Kazakhstan.

Inanibigutta (?) *minuta* Wang, 1993
(Fig. 4F-G)

Inanibigutta minuta Wang, 1993: 100, pl. 6, figs 9-12.

OCCURRENCE. — Middle part of the Pingliang Formation, Gansu Province, China (Wang 1993); grey radiolarites of the Crawford track, Southern Uplands, this study.

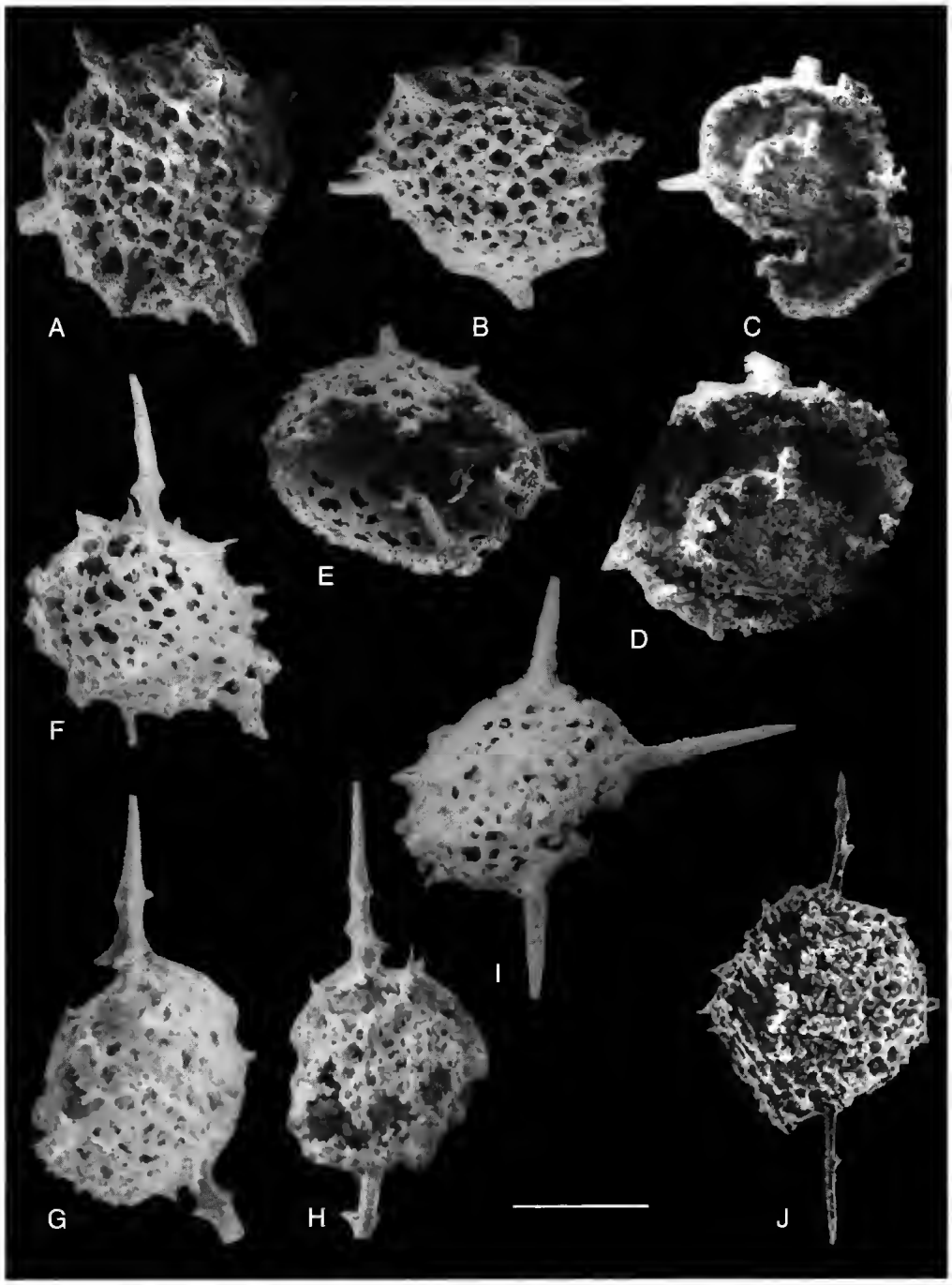

FIG. 4. — Scanning electron micrographs of radiolaria extracted from cherts of the Southern Uplands. **A-D**, *Inanibigutta diffusa* (Hinde), different views of the same specimen; **C-D**, view of internal structure after the shell was broken with a razor; **E**, ? *Inanibigutta diffusa* (Hinde); **F-G**, *Inanibigutta* (?) *minuta* Wang; **H**, *Inanibigutta* sp. cf. *I. verrucula* (Nazarov); **I**, *Inanibigutta* sp. cf. *I. aksakensis* (Nazarov); **J**, *Inanibigutta* (?) sp. A. Scale bar: A, 82 µm; B, 89,5 µm; C, 106 µm; D, 70 µm; E, 76 µm; F, G, 94 µm; H, 124 µm; I, 83 µm; J, 129 µm.

REMARKS
The observed morphotypes are identical to *Inanibigutta minuta* as described and illustrated by Wang (1993). They possess nearly spherical outer shells with numerous secondary spines, distally tapering main spines with apophyses in their proximal part and both the outer shell and main spines have appropriate dimensions. Nevertheless, the attribution of this species to *Inanibigutta* is questionable because in neither the type-series (holotype and paratypes), nor in our material has the exact number of main spines ever been observed.

Inanibigutta sp. cf. ***I. Verrucula***
(Nazarov *in* Nazarov & Popov, 1976)
(Fig. 4H)

Entactinosphaera verrucula Nazarov *in* Nazarov & Popov, 1976: 408-409, fig. 1d. – Nazarov & Popov 1980: 38-39, text-fig. 17, pl. 3, fig. 6, pl. 11, fig. 6.
Inanibigutta verrucula (Nazarov) – Nazarov 1988, fig. 31. – Wang 1993: 100, pl. 6, figs 2-3, 5-8.

OCCURRENCE. — Middle part of the Pingliang Formation, Gansu Province, China (Wang, 1993); grey radiolarites of the Crawford track, Southern Uplands, this study.

REMARKS
The illustrated specimen is comparable to *I. verrucula* as described originally by Nazarov (1976). The spherical outer shell (diameter: 185 µm) is perforated by angular to subangular pores and bears short conoidal secondary spines, as well as main spines (length of intact spine: 174 µm). However, it differs as main spines are tapering rather than cylindrical and apophyses tend to be clustered near the proximal part of the spines. My material resembles Wang's (1993) specimens in all respects. This species can be distinguished from *I.* (?) *minuta* Wang by the larger size of its outer shell, of diameter usually greater than 180 µm, and by the longer main spines (> 150 µm).

Inanibigutta sp. cf. ***I. aksakensis*** (Nazarov, 1975)
(Fig. 4I)

Entactinosphaera aksakensis Nazarov, 1975: 68, pl. 16, figs 4-8, pl. 21, fig. 1 (not 2). – Nazarov & Popov 1980: 35, 36, text-fig. 15a-b, pl. 3, figs 8, 9, pl. 8, fig. 6, pl. 11, figs 8, 9.
Inanibigutta aksakensis (Nazarov) – Nazarov 1988, text-fig. 17, pl. 10, fig. 7-8. – Nazarov & Ormiston 1993: 36, pl. 3, fig. 1.

OCCURRENCE. — Grey radiolarites of the Crawford track, Southern Uplands, this study.

REMARKS
This morphotype has distally tapering main spines, small secondary spines on the perforated outer shell and an inner spherical shell (diameter: 70 µm approximately) comparable to *I. aksakensis*. However, the size of the outer shell (diameter less than 150 µm) is nearly half the size of the latter species. The holotype of *I. aksakensis* in Nazarov's (1975) work is the specimen illustrated on pl. 21, fig. 1 (see pl. 3, fig. 8 *in* Nazarov & Popov 1980).

Inanibigutta (?) sp. A
(Fig. 4J)

OCCURRENCE. — Red-brown radiolarites at Hawkwood Burn, Southern Uplands, this study.

DESCRIPTION
The outer shell is a nearly perfect sphere perforated by relatively large circular pores. It also bears small secondary spines. Two thin rod-like main spines, positioned along an axis and almost half the length of the diameter of the outer shell, display a few thorn-shaped apophyses.

REMARKS
The nature of the thin rod-like main spines distinguishes this morphotype from all other Inaniguttidae. The exact number of spines and internal structure of the shell are unknown.

Genus *Inanigutta* Nazarov & Ormiston, 1984

Inanigutta Nazarov & Ormiston, 1984: 72, 86. – Nazarov 1988: 56.

TYPE SPECIES. — *Entactinia unica* Nazarov, 1975.

Inaniguttа (?) sp. K
(Fig. 5A)

OCCURRENCE. — Grey radiolarites of the Crawford track, Southern Uplands, this study.

DESCRIPTION
Small inaniguttid with six robust main spines, four of them situated on an equatorial plane and the other two along an axis perpendicular to it. The four equatorial spines are themselves positioned along two axes, perpendicular to each other. All spines are rod-like, gently tapering distally. Their bases are large, perforated and joined to the outer perforated shell in such a way as to give a bipyramidal outline. No secondary spines are visible on the surface of the outer shell.

REMARKS
Uncertainty regarding generic assignement is due to the unknown internal structure of this morphotype.

Genus *Oriundogutta* Nazarov, 1988

Oriundogutta Nazarov, 1988: 57. – Nazarov & Ormiston 1993: 36, text-fig. 7b.

TYPE SPECIES. — *Astroentactinia ramificans* Nazarov, 1975.

?*Oriundogutta rüsti*
(Ruedemann & Wilson, 1936)
(Fig. 5B)

? *Heliosphaera rüsti* Ruedemann & Wilson, 1936: 1572, pl. 5, figs 13-15, 31, pl. 7, fig. 8.
? *Astroentactinia* ? *rüsti* (Ruedemann & Wilson) – Nazarov & Popov 1980: 46, text-fig. 24, pl. 12, figs 10-11.

OCCURRENCE. — Red-brown radiolarites at Hawkwood Burn, Southern Uplands, this study.

REMARKS
The size of the outer shell (diameter 150 µm approximately) and the presence of stout and thinner spines are comparable to *O. rüsti*. Doubts regarding taxonomic assignement remain owing to uncertainty about the internal structure.

?*Oriundogutta bella* Wang, 1993
(Fig. 5C)

? *Oriundogutta bella* Wang, 1993: 101, pl. 9, figs 1-13.

OCCURRENCE. — Grey radiolarites of the Crawford track, Southern Uplands, this study.

REMARKS
Although only six spines are visible, their distribution and angle on the spherical shell suggests that their total number is possibly eight.

Inaniguttid (?) gen. et sp. indet.
(Fig. 5D-E)

OCCURRENCE. — Grey radiolarites of the Crawford track, Southern Uplands, this study.

DESCRIPTION
Star-shaped shell, lenticular in cross-section, bearing five robust conical spines. The shell is perforated by numerous pores of various sizes and shapes (subangular, oval). Pores near the base of the spines are distinctly larger and elongated, encompassing part of the spine. The internal structure is unknown.

Order ALBAILLELLARIA Deflandre, 1953
emend. Holdsworth, 1969
Family CERATOIKISCIDAE Holdsworth, 1969

Genus *Protoceratoikiscum*
Goto, Umeda & Ishiga, 1992

Protoceratoikiscum Goto, Umeda & Ishiga, 1992: 165.

TYPE SPECIES. — *Protoceratoikiscum chinocrystallus* Goto, Umeda & Ishiga, 1992.

Protoceratoikiscum sp.
aff. *P. similistellatum* Li, 1995
(Fig. 5F-G)

aff. *Protoceratoikiscum similistellatum* Li, 1995: 337, pl. 2, figs 2, 4.

OCCURRENCE. — Grey radiolarites of the Crawford track, Southern Uplands, this study.

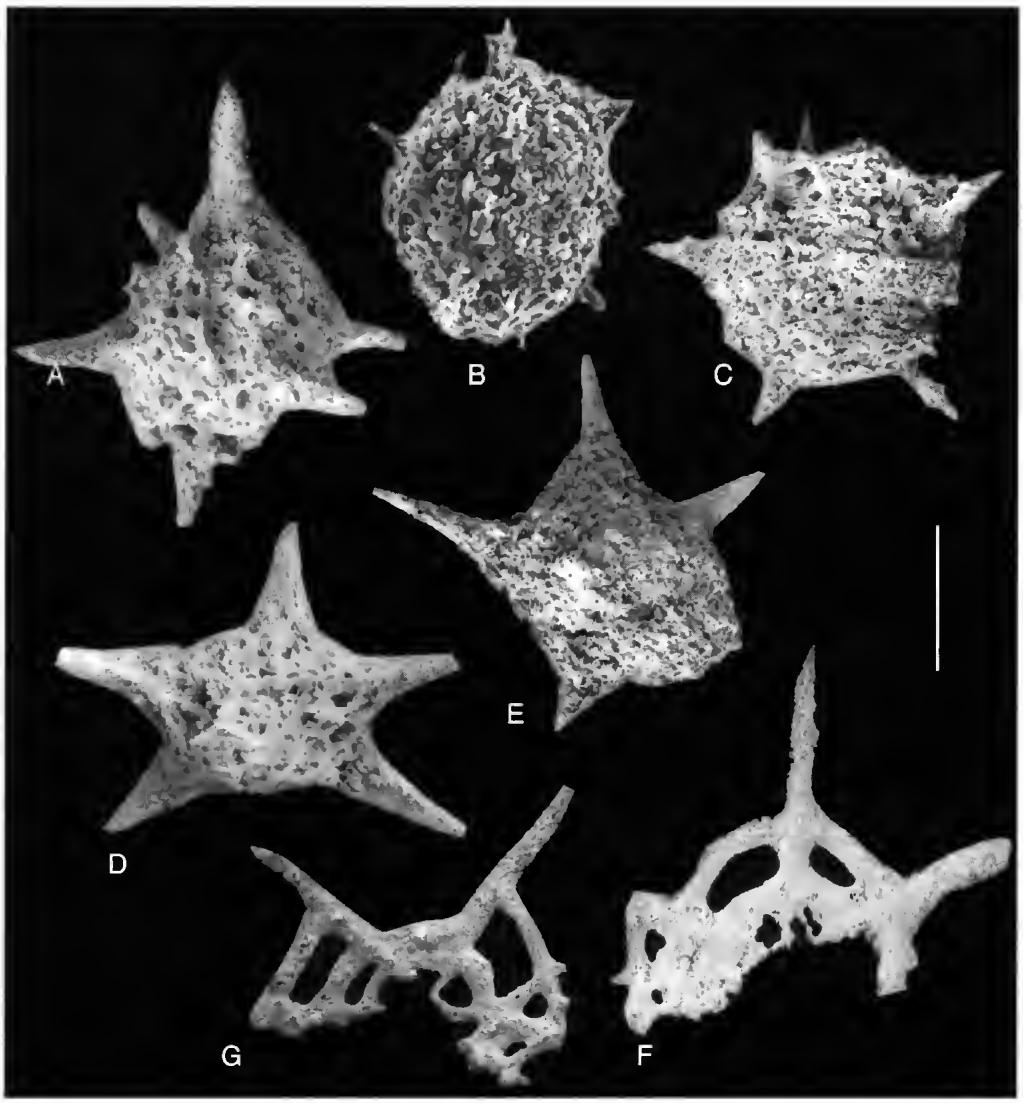

FIG. 5. — Scanning electron micrographs of radiolaria extracted from cherts of the Southern Uplands. **A**, *Inanigutta* (?) sp. K; **B**, ? *Oriundogutta rüsti* (Ruedemann & Wilson); **C**, ? *Oriundogutta bella* Wang; **D-E**, Inaniguttid (?) gen. et sp. indet.; **F-G**, *Protoceratoikiscum* sp. aff. *P. similistellatum*. Scale bar: A, 51 µm; B, 79 µm; C, 73 µm; D, 65 µm; E, 72 µm; F, 63 µm; G, 66.5 µm.

DESCRIPTION

Three to four spines distributed radially along a semi-circle formed by two to three rows of arches joining the spines. Spines taper gently distally, but also towards the centre very rapidly.

REMARKS

From the presence of arches between spines this morphotype is comparable to the species described by Li (1995). However, it differs in its smaller size and the smaller angle between adjacent spines. Only incomplete specimens were encountered in the yielded material.

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Radiolarians as tracers for provenance of gravels in Lower Cretaceous molasse (Outer Zone of SW Japan)

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ABSTRACT

This paper discusses the results and the recent status of the study by radiolarians as tracers for erosional events, especially for those of Jurassic and pre-Jurassic accretionary complexes in the Outer Zone of SW Japan. As a test case to clarify the provenance of radiolarian-bearing gravels in conglomerates, the author reviewed the work previously done to trace the source rocks within oceanic-plate stratigraphy successions from monomictic chert-pebble conglomerates of the Lower Cretaceous Ryoseki-Monobegawa group. The group is a molasse typical of paralic sedimentary facies in the Outer Zone of SW Japan.

KEY WORDS
Provenance,
conglomerate,
molasse,
radiolarian dating,
Jurassic accretionary complex,
Cretaceous,
SW Japan.

RÉSUMÉ

De l'utilisation des radiolaires comme indicateurs de provenance des graviers dans les molasses crétacées inférieures (zones externes du SW Japon).

Le présent article discute des implications qu'a l'utilisation récente des radiolaires comme indicateurs d'événements érosifs, en particulier de ceux de complexes d'accrétion jurassiques et anté-jurassiques au SW Japon. Comme étude de cas pour éclairer la provenance de graviers à radiolaires des conglomérats, l'auteur effectue une revue des séries stratigraphiques synthétiques à partir des conglomérats monogéniques à galets de cherts du groupe Ryoseki-Monobegawa du Crétacé inférieur. Ce groupe molassique est de faciès sédimentaire paralique typique des zones externes du SW Japon.

MOTS CLÉS
Provenance,
conglomérat,
molasse,
datation par radiolaires,
complexes
d'accrétion jurassiques,
Crétacé,
SW Japon.

INTRODUCTION

In the last two decades, radiolarian researchers in Japan made an effort to clarify the Permian, Triassic and Jurassic biostratigraphy, and established many radiolarian biostratigraphic zones (e.g., Ishiga 1986, 1990; Matsuoka & Yao 1986; Yao 1990; Matsuoka 1995 etc.) within accretionary complexes (AC; Taira *et al.* 1981). They analyzed bed by bed the faunas from blocks of pelagic sediments in melanges and olistostromes. It contributed to reconstruct the oceanic plate stratigraphy (OPS) from these tectonically disrupted sedimentary rocks (e.g., Matsuoka 1984; Ishida 1987; Hada & Kurimoto 1990; Isozaki 1997a), as well as to distinguish geologic units and to clarify their spatial distribution (Mizutani 1995).

Radiolarians are important indexes for the Paleozoic and the Mesozoic. Their size averages 10^{-1} mm. They are therefore small enough to be reworked as an inclusion into clasts of various size and even in sand grains. This property is effective to analyse erosional events. Radiolarians are available for identifying source rocks of clastics.

The "clastic approach" of radiolarian dating appears particularly appropriate for chert-bearing terrane analysis of the Canadian Cordillera (Cordey 1992). In case of California Coast Ranges, analysis of radiolarian chert-pebbles is more effective than sandstone component not only for the provenancial study but also for clarifying the tectonic movement along the transform fault (Seiders & Blome 1984, 1988).

This paper deals with erosional events following the setting of accretionary complexes. This is one test case in the reconstruction of OPS from the gravels and clasts in the monomictic conglomerates. In this case, radiolarians in gravels are used as tracers for erosional events. This type of test will become a great help to study the orogenic and/or erosional events in the marginal area of the Late Mesozoic East Asian continent.

GEOLOGY OF SW JAPAN

With respect of the continuity of the pre-Neogene orogenic units and ACs, at least the southwest side of the Tanakura Tectonic Line is regarded as SW Japan. The post-Neogene geological province of SW Japan is subdivided into the Inner Zone on the continental side and the Outer Zone on the trench side by the Median Tectonic Line (MTL). Based on a paleobiogeographical study, the left-lateral slip movement along the MTL is regarded to reach about 1500 km after the Early Cretaceous time (Tazawa 1993). Concerning the pre-Neogene geology, nappes and klippes of the Permo-Triassic orogenic units and Jurassic ACs are distributed in the Inner and the Outer zones of SW Japan (Fig. 1). The Inner Zone of SW Japan is composed of the Hida, Marginal Hida, Akiyoshi, Sangun, Maizuru, Ultra-Tamba, and the Mino-Tamba belts from the north to the south.

The Hida Belt is mainly composed of gneisses with intrusion of Permian-Jurassic granites. The Tetori group of the Middle Jurassic-Lower Cretaceous shallow-marine and non-marine formations unconformably overlies these gneisses and granites. The Hida Belt is situated in the most continental side of SW Japan, and is supposed to thrust on the Akiyoshi, Sangun, Maizuru and the Ultra-Tamba belts.

The Marginal Hida Belt is situated between the Hida and the Mino-Tamba belts. It is supposed to thrust upon the Mino-Tamba Belts together with the Hida Belt. The Marginal Hida Belt is composed of Paleozoic complex with Triassic formation that are unconformably overlain by the Lower-Middle Jurassic Kuruma group. The Paleozoic complexes appear to be serpentinite melanges that include blocks of glaucophane schists, amphibolites, Early-Late Paleozoic clastic sediments with limestones.

The Akiyoshi Belt is composed of the Middle-Late Paleozoic ACs and the Mesozoic cover formations. The Late Paleozoic ACs contain large blocks of Carboniferous and Permian limestones with basalts as well as blocks of Permian cherts, mudstones and sandstones. The Mesozoic shallow-marine and brackish cover formations are the Triassic Natiwa group and the Jurassic Yamaoku formations.

The Sangun Belt is mainly composed of 180-230 Ma glaucophane schists and slates that are

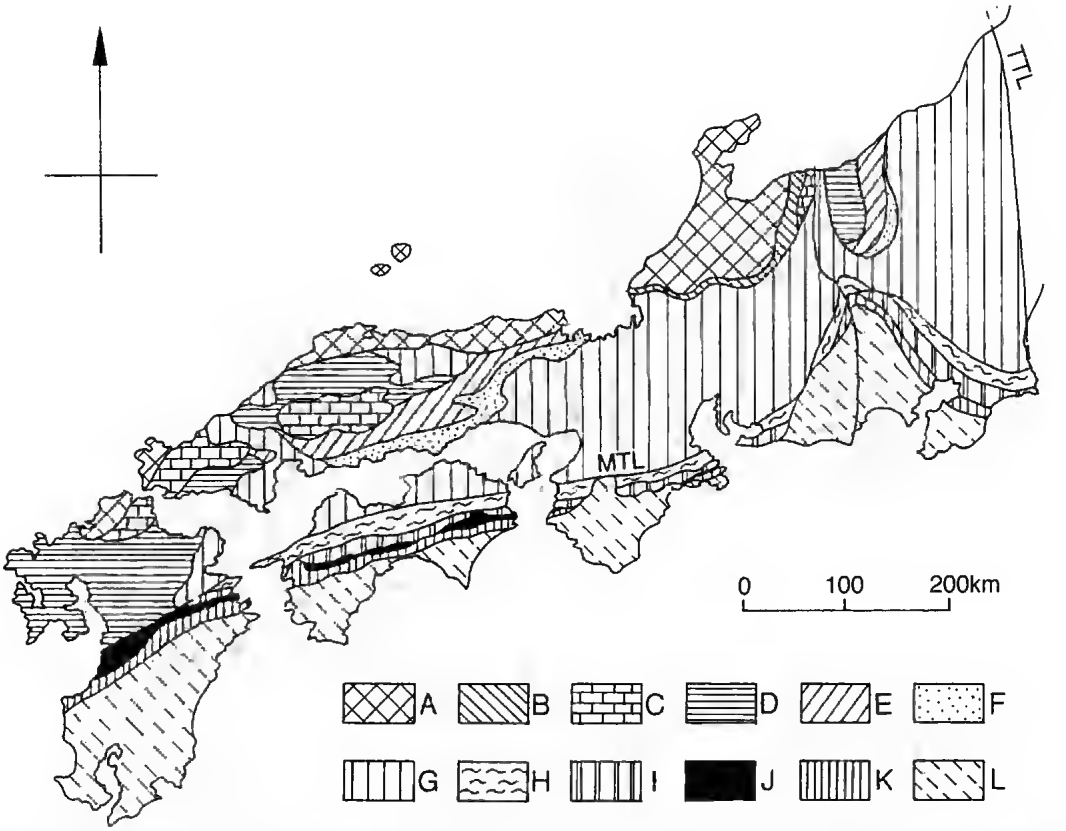

FIG. 1. — Zonal distribution of pre-Neogene orogenic units and accretionary complexes in SW Japan. **A**, Hida; **B**, Marginal Hida; **C**, Akiyoshi; **D**, Sangun; **E**, Maizuru; **F**, Ultra-Tamba; **G**, Mino-Tamba belts of the Inner Zone; **H**, Sambagawa-Mikabu; **I**, North Chichibu; **J**, Kurosegawa; **K**, South Chichibu belts; **L**, Shimanto Superbelts of the Outer Zone. **MTL**, Median Tectonic Line; **TTL**, Tanakura Tectonic Line.

originated from mudstones, sandstones, and basalts with cherts of the Late Permian ACs.

The Maizuru Belt is composed of Paleozoic basic rocks (Yakuno ophiolite) and Middle-Late Permian slope basin deposits (Maizuru group) that are unconformably overlain by the Lower-Middle Triassic Yakuno group.

The Ultra-Tamba Belt is subdivided into three nappes. The highest nappe of the UT3 is composed of Upper Permian mudstones and greenstones with cherts and Upper Carboniferous limestones. Intermediate nappe of the UT2 is composed of Upper Permian siliceous mudstones with Lower-Middle Permian bedded cherts. The lowest nappe of the UT1 is composed of Middle-Late Permian mudstones and greenish sandstones. The Permian formations of the UT1 are unconformably overlain by the non-marine Lower Cretaceous Sasayama group.

The Mino-Tamba Belt is composed mainly of the Early Jurassic-earliest Cretaceous ACs that are intruded by the Late Cretaceous Ryoke granites. They are unconformably overlain by the Late Cretaceous volcano-clastic formations (Nohi rhyolites) and the Paleogene non-marine conglomerates. The Early Jurassic-earliest Cretaceous ACs are subdivided into several tectonic units. They are composed of Permian, Middle-Upper Triassic and Lower-Middle Jurassic cherts with Early Triassic siliceous claystones, Jurassic-earliest Cretaceous mudstones and turbidites. These ACs also contain blocks of Upper Paleozoic limestones and basaltic greenstones.

The Outer Zone of SW Japan is composed of the Sambagawa-Mikabu, North Chichibu, Kurosegawa, South Chichibu belts and the Shimanto Superbelt from the north to the south.

The Sambagawa-Mikabu Belt is composed of the Sambagawa crystalline schists and the Mikabu greenstones. This belt is supposed to consist of the Early Jurassic-Early Cretaceous ACs. Multiple nappe structure is characteristic in this belt. The Sambagawa crystalline schists are composed of basic and pelitic schists with quartz and psammitic schists. Some of the intercalated calcareous schists in the basic schists are originated from the Upper Triassic limestones (Suyari *et al.* 1980a). The Mikabu greenstones are composed of low-metamorphosed gabbros, dolerites, pillow basalts and basaltic hyaloclastites with Upper Jurassic cherts (Faure *et al.* 1991), mudstones and Upper Triassic limestones. They experienced H-P/L-T metamorphism during the Cretaceous. Metamorphic grade is higher in the northern nappes.

The geometry of the Kurosegawa Belt with respect to the Jurassic AC is not yet settled sufficiently. However, after the Early Cretaceous time, the non-metamorphosed Jurassic AC and the pre-Jurassic AC of the Outer Zone of SW Japan are distributed in a terrane that is called the Chichibu Superterrane. The Chichibu Superterrane is subdivided into the pre-Jurassic AC of the Kurosegawa Belt, and the Jurassic AC of the North Chichibu and the South Chichibu belts.

The Kurosegawa Belt is situated in the central part of the Chichibu Superterrane, and is composed of the Paleozoic AC that is unconformably overlain by the Mesozoic cover formations. This belt is subdivided into the north and the south units. In the south unit, pre-Jurassic AC is composed of Permian and Middle Paleozoic formations that are unconformably overlain by shallow marine and paralic formations of the Middle-Upper Triassic *Daonella-Monotis* beds, Middle-Upper Jurassic Torinosu group and the Lower Cretaceous Takegatani group. The Permian formations are melanges and slope basin facies. The Middle Paleozoic fromations appears with serpentinites as lenticular bodies that are composed of gneisses, granites and the Silurian limestones. The north unit is composed of the Permian AC that is unconformably overlain by the Lower Cretaceous paralic formations of the Ryoseki-Monobegawa group. The north unit lacks the Middle Paleozoic formations and the Triassic-Jurassic cover formations.

The North Chichibu Belt (NCB) is distributed in the north side of the Chichibu Superterrane. The NCB is composed of latest Triassic-Middle Jurassic ACs that consist of Permian, Middle-Upper Triassic and Lower Jurassic cherts with the Early Triassic siliceous claystones, Lower-Middle Jurassic mudstones and turbidites. These ACs also contain blocks of the Upper Paleozoic limestones and basaltic greenstones.

The South Chichibu Belt (SCB) is composed of Middle Jurassic-earliest Cretaceous ACs (Nakagawa group) and the Late Jurassic-Early Cretaceous slope basin formations of the Torinosu group. The Middle Jurassic-earliest Cretaceous ACs are subdivided into several tectonic units that have the accretion polarity rejuvenating from the north to the south. They are composed of Permian, Middle-Upper Triassic and Lower-Middle Jurassic cherts with the Early Triassic siliceous claystones, Middle Jurassic-earliest Cretaceous mudstones and turbidite sandstones. These ACs also contain Upper Paleozoic limestones and basaltic greenstones.

The Shimanto Superbelt is subdivided into the North Shimanto Belt (NSB) and the South Shimanto Belt (SSB). The NSB is composed of late Early-Late Cretaceous ACs and slope basin formations. These ACs contain the Lower-Upper Cretaceous cherts, and the Izuhara and Hayama slope basin formations contain olistoliths of the Triassic limestones from the SCB. The SSB is composed of the Paleogene-Miocene ACs and the slope-basin formations.

GEOLOGICAL SETTING

A nappe model of the SW Japan was proposed when the recent radiolarian works in Japan has started (Faure 1983a, b). At first, the Kurosegawa Belt was proposed to be a lower unit as a remnant of the subducted microcontinent (Faure 1985; Caridroit & Charvet 1986). In comparison with the geology of the Inner Zone of SW Japan, the Kurosegawa Belt was proposed to be a klippe above the Chichibu Klippe (Isozaki *et al.* 1992). According to Suzuki & Itaya (1994), the

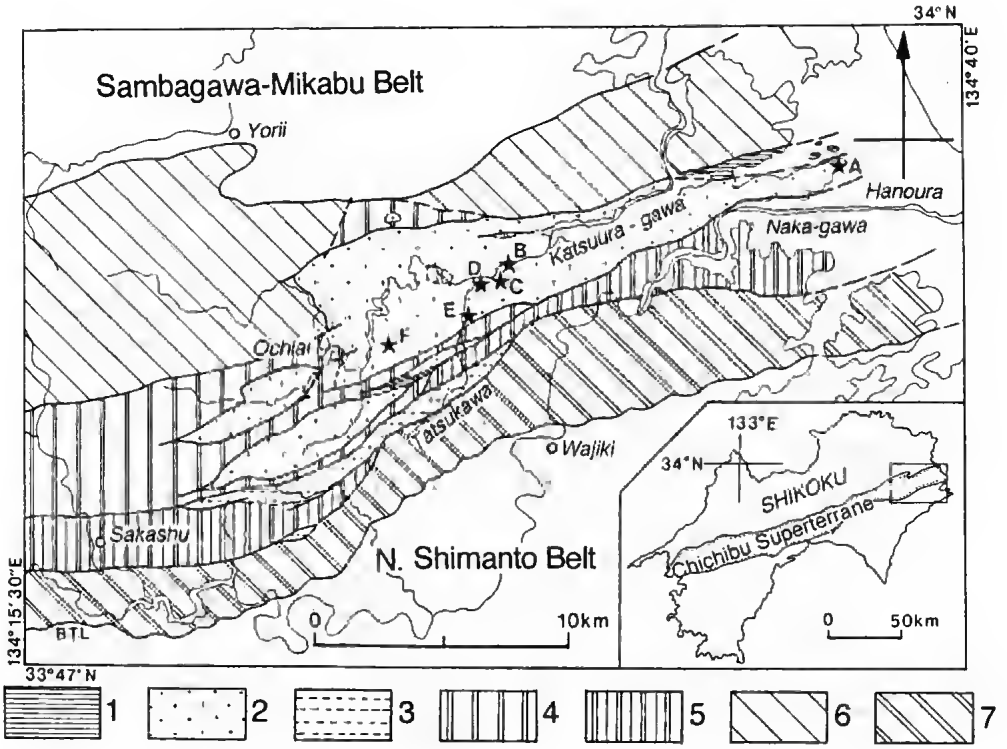

FIG. 2. — Geological outline map of the Chichibu Superterrane. 1, Sotoizumi group (Upper Cretaceous slope basin sediments); 2, Ryoseki-Monobegawa group (Lower Cretaceous paralic sediments); 3, Takegatani group (Lower Cretaceous shallow marine sediments); 4, north unit of the Kurosegawa Belt (Permian accretionary complex); 5, south unit of the Kurosegawa Belt (Permian accretionary complex with Middle Paleozoic blocks and Triassic-Jurassic cover formations); 6, North Chichibu Belt (Lower-Middle Jurassic accretionary complex); 7, South Chichibu Belt (Middle Jurassic-Early Cretaceous accretionary complex).

K-Ar ages of the pre-Jurassic AC in the Kurosegawa Belt are Late Triassic to Early Jurassic (194-225 Ma). The K-Ar ages of the Jurassic AC in the North Chichibu Belt are Middle Jurassic to earliest Cretaceous.

The Ryoseki-Monobegawa group in the Outer Zone of SW Japan is characteristic of paralic facies of the Early Cretaceous age (Tashiro 1986; Tashiro & Kozai 1991; Kozai 1996; Ishida *et al.* 1992, 1996). The group unconformably overlies pre-Jurassic (Permian) melanges of the north unit of the Kurosegawa Belt (Ishida *et al.* 1992). The Kurosegawa Belt is subdivided into the north and the south units. They are situated between the Jurassic AC of the North and the South Chichibu belts (Fig. 2). In the south unit, pre-Jurassic AC with blocks of gneisses, granites and Silurian limestones is unconformably overlain by the Triassic shallow-marine formations (Sakashu unconformity: Ichikawa *et al.* 1953). Thus, thin shallow-marine Triassic and Jurassic formations overlie the Paleozoic complexes in the South Kurosegawa unit, whereas they never distribute in the north unit. The Ryoseki-Monobegawa group and the equivalent Takegatani group unconformably overlie both units of the Kurosegawa Belt. The group is composed of brackish conglomerates and shallow-marine sediments. They yield autochthonous Barremian mollusks (Matsukawa & Eto 1987).

The Lower Cretaceous formations of the Ryoseki-Monobegawa group are composed mainly of conglomerates, sandstones and mudstones with seams of tuffs, limestones and coals (Fig. 3). In East Shikoku, the group is subdivided into the Tatsukawa, Lower and Upper Hanoura, Hoji and Fujikawa formations (Ishida *et al.* 1992, 1996). These formations yield

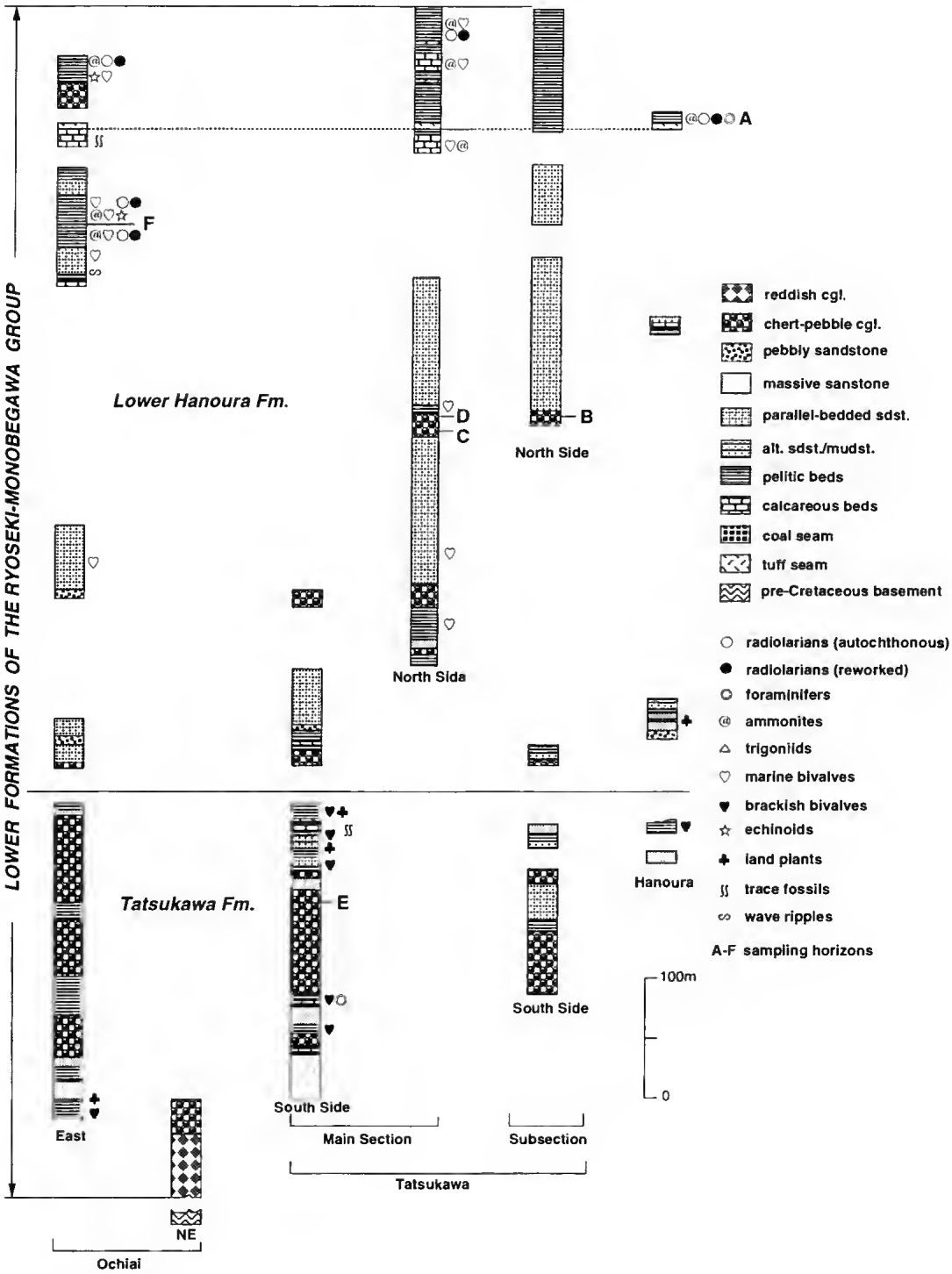

FIG. 3. — Stratigraphic columns of the lower formations of the Ryoseki-Monobegawa group in East Shikoku.

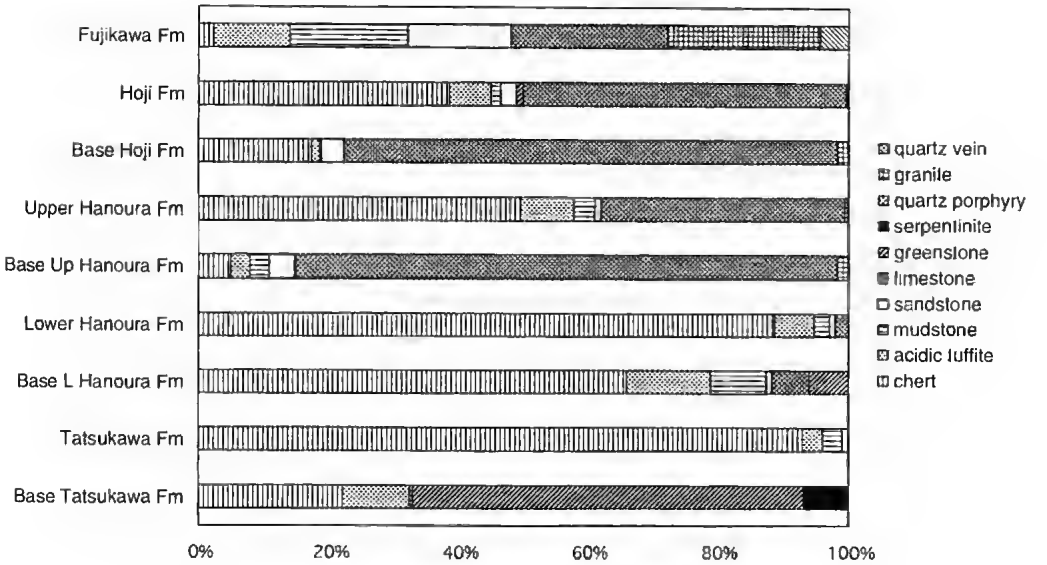

FIG. 4. — Composition and vertical change of gravels in the Ryoseki-Monobegawa group, East Shikoku.

autochthonous ammonites, bivalves, echinoids, foraminifers and radiolarians with allochthonous plants, non-marine bivalves and dinosaur teeth. They indicate Barremian to Albian ages. The radiolarian zonation of the Ryoseki-Monobegawa group is subdivided into the *Archaeodictyomitra pseudoscalaris* (Barremian), *Stichomitra communis* (upper Aptian) and *Pseudodictyomitra pentacolaensis* (middle Albian) assemblage zones in ascending order (Ishida & Hashimoto 1991a). These zones are calibrated by co-occurring ammonites. These formations form sedimentary cycles that are characterized by upward thinning and fining sequences under the effect of transgressive events. Growth of the deltaic fan is synchronous with the eustatic change. The conglomerates are more than 100 m thick, and are frequently intercalated in many horizons (Fig. 3).

Characteristics of the conglomerates, especially the size, roundness, lithology and sorting of the gravels differ in horizons. Basal conglomerate of the group is characterized by basaltic greenstone gravels and serpentinite blocks that are interpreted as the result of debris flows. Round gravels of quartz-porphyry and fine granite increase in the upper horizons, especially above the Upper Hanoura formations. In the upper part of the Tatsukawa formation and the Lower Hanoura formation, there are many chert-pebble conglomerate beds of monomictic origin (Fig. 4). The chert-pebble conglomerates are composed of round chert pebbles of a few cm in diameter that occupy more than 90% of the gravels (Fig. 4). They are well sorted, and clast-supported. For this study, the author studied these monomictic chert-pebble conglomerates with special respect to reconstruct the provenancial OPS, and extracted radiolarians from chert pebbles and mudstone clasts.

PREPARATION AND PROCESSING OF SAMPLES

This study needs some information about OPS of sedimentary basements and/or terranes of origin from radiolarian-bearing gravels in monomictic conglomerates. For this purpose, it is necessary to clarify the relationship between the lithology of gravels and their radiolarian ages. Particularly, reconstructing the OPS of terranes from gravels in monomictic conglomerates requires to be able to distinguish the lithology of gravels, whether they are of pelagic or continental origin, as well as to determine their radio-

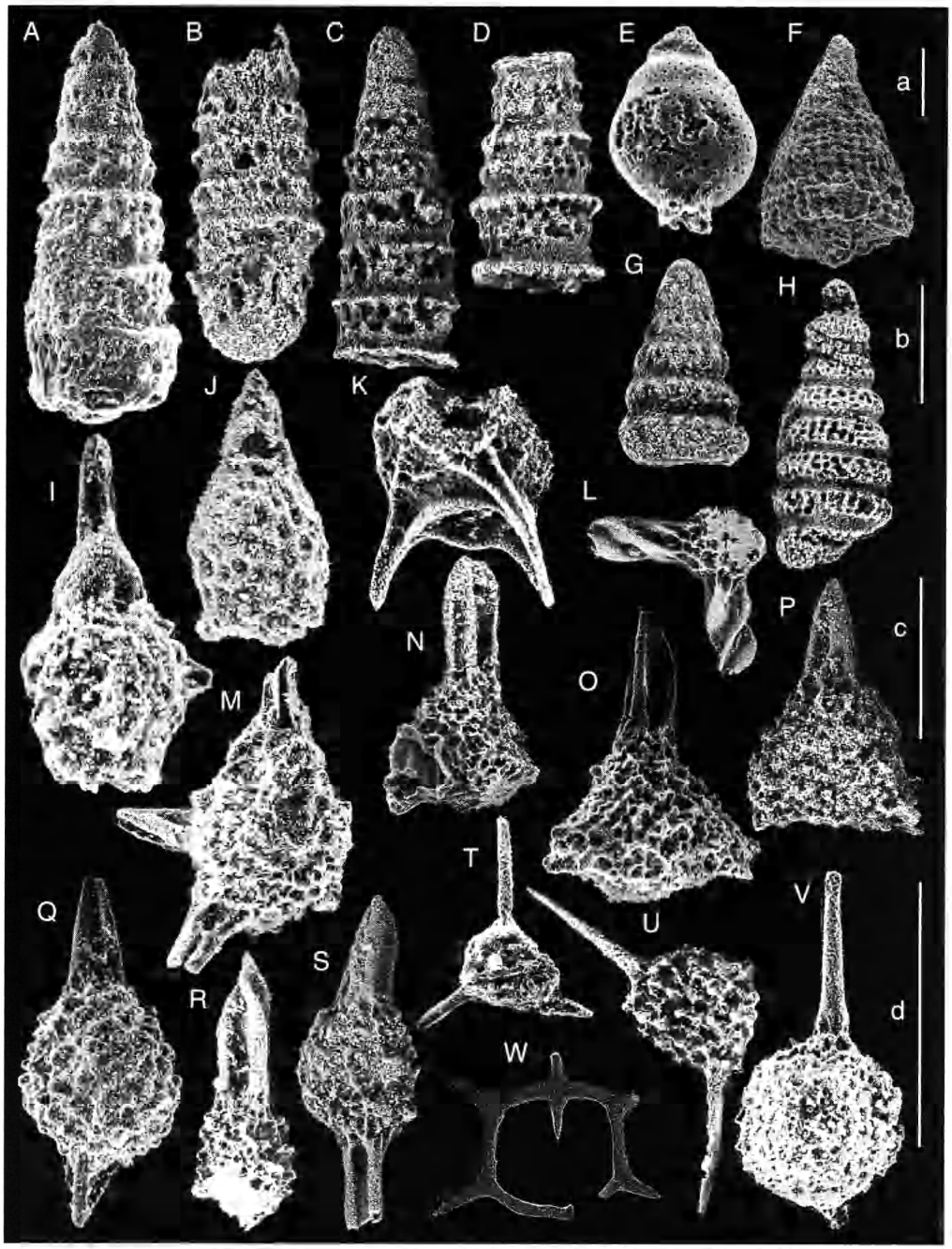

FIG. 5. — Middle-Late Triassic and earliest Jurassic radiolarians from the chert pebbles of the Ryoseki-Monobegawa group in East Shikoku. **A**, *Triassocampe longicephalis* Kozur & Mostler; **B**, *Annulotriassocampe campanilis* Kozur & Mostler; **C**, **D**, *Triassocampe* aff. *scalaris* Dumitrica, Kozur & Mostler; **E**, *Gigi fustis* De Wever; **F**, *Parahsuum simplum* Yao; **G**, *Corum speciosum* Blome; **H**, *Pararuesticyrtium mediotassanicum* Kozur & Mostler; **I**, *Hindedorcus holdsworthi* Sugiyama; **J**, *Theocorys* sp. A of Nakaseko & Nishimura; **K**, *Hozmadia reticulata* Dumitrica, Kozur & Mostler; **L**, *Tiborella cochleata* (Nakaseko & Nishimura); **M**, *Betunella robusta* Dumitrica, Kozur & Mostler; **N**, *Eptingium manfredi robustum* Kozur & Mostler; **O**, *Eptingium nakasekoi* Kozur & Mostler; **P**, *Eptingium* cf. *manfredi* Dumitrica; **Q**, *Pseudostylosphaera spinulosum* (Nakaseko & Nishimura); **R**, *Pseudostylosphaera* sp. C of Kojima & Mizutani, 1987; **S**, *Pseudostylosphaera japonica* (Nakaseko & Nishimura); **T**, *Capnodoce sarisa* De Wever; **U**, *Tolonche japonica* Nakaseko & Nishimura; **V**, *Sarla* (?) *externa* Blome; **W**, *Acanthocircus vigrassi* Blome. Scale bars: 100 µm; **a**, W; **b**, H, L-P, R-V; **c**, A-G, J, K, Q; **d**, I.

larian age. In the marginal area of East Asia and Japanese Islands, Jurassic and pre-Jurassic ACs originate from OPS that are mainly composed of chert-clastic sequences. In these chert-clastic sequences, sediments start from pelagic bedded cherts, and they gradually change upwards towards alternating beds of turbidite sandstones and mudstones (trench-fill turbidite) by way of hemipelagic siliceous mudstone beds.

Regarding the conglomerates in the Lower Cretaceous Ryoseki-Monobegawa group, the following method of processing is used. If gravels are larger than 20 mm in diameter, and it is easy to isolate them from the matrix, gravels of cherts and mudstones are chemically processed separately. If gravels are too small (less than 20 mm in diameter) and difficult to isolate separately from the hard matrix, slabs of conglomerates about 5 mm thick are made. Then, gravels are cut off using pliers. After that, the fragments of pebbles are classified lithologically into cherts or mudstones. In the Ryoseki-Monobegawa group, the matrices of conglomerates are usually composed of sandstones. They contain not only chert clasts but also mudstone grains that are less than 2 mm in diameter. In the study, the matrices of conglomerates are separated from the gravels before processing. This method shows that the matrices yield quite different kind of radiolarians abundantly compared with those from the chert gravels. The samples were processed by 3-7% diluted HF for about 12 hours. The process was repeated several times.

RADIOLARIAN AGE OF GRAVELS AND CLASTS

The chert gravels of chert-pebble conglomerates of the Ryoseki-Monobegawa group yield Middle-Late Triassic, and earliest Jurassic radiolarians (Fig. 5). Among them, *Hindedorcus holdsworthi*, *Eptingium nakasekoi*, *E.* cf. *manfredi*, *Triassocampe* aff. *scalaris*, *Annulotriassocampe campanilis*, *Trilonche japonica*, *Pseudostylosphaera japonica*, *Beturiella robusta*, *Pseudostylosphaera spinulosum*, *P.* sp. C of Kojima & Mizutani (1987), *Triassocampe longicephalis*, *Pararuesticyrtium mediofassanicum*, *Hozumadia reticulata*, *Tiborella cochleata* are characteristic of the Middle Triassic. *Hindedorcus holdsworthi* was reported from the chert beds of the Kinkazan, Mino-Tamba Belt (Sugiyama 1992). This species is characteristic in *Hozmadia gifuensis* assemblage of the early Anisian age. *Eptingium nakasekoi* was reported from the *Paraceratites trinodosus* zone (Illyrian) in the Balaton Hills, Hungary (Kozur & Mostler 1994). *Eptingium* cf. *manfredi* is closely related with the same species that was reported from the bedded chert sequences in the Inuyama area of the Mino-Tamba Belt. The species occurs with *Triassocampe deweveri* and Ladinian conodonts (Yao 1982). *Triassocampe* aff. *scalaris* co-occurs with Anisian conodonts from the chert beds of the South Chichibu Belt (Ishida 1984). *Annulotriassocampe campanilis* was reported from the Fassan beds of the Balaton Hills, Hungary (Kozur & Mostler 1994). *Trilonche japonica* co-occurred with *Triassocampe deweveri* in the chert of the South Chichibu Belt (Nakaseko & Nishimura 1979). *Pseudostylo-sphaera japonica* was described from the chert beds of the South Chichibu Belt (Nakaseko & Nishimura 1979). This species co-occurs with *Neogondolella haslachensis* in the late Anisian-early Ladinian chert beds of the Sikhote-Alin and Sakhalin (Bragin 1991). Another reports on occurrences are from bedded cherts in the Mino-Tamba Belt (Yao 1982) and the Nadanhada, NE China (Kojima & Mizutani 1987). *Beturiella robusta* was reported from the "*Nodosus* bed" about the Anisian/Ladinian boundary in the southern Dolomiten Alps (Dumitrica *et al.* 1980). *Pseudostylosphaera spinulosum* was reported from chert beds of the South Chichibu Belt (Nakaseko & Nishimura 1979), and from the upper Anisian-lower Ladinian chert beds in the northernmost Sakhalin with *Pseudostylosphaera japonica* (Bragin 1991). *Pseudostylosphaera* sp. C of Kojima & Mizutani (1987) has slightly twisted polar spines. This species was reported from the late Anisian to Ladinian bedded chert in the Nadanhada Range. *Triassocampe longicephalis* is described in the early Ladinian (middle Fassanian) beds of the Vincentinian Alps, Italy (Kozur & Mostler 1994). *Pararuesticyrtium mediofassanicum* is known in the *Ladinocampe multiperforata* zone of the middle Fassanian beds in the Vincentinian

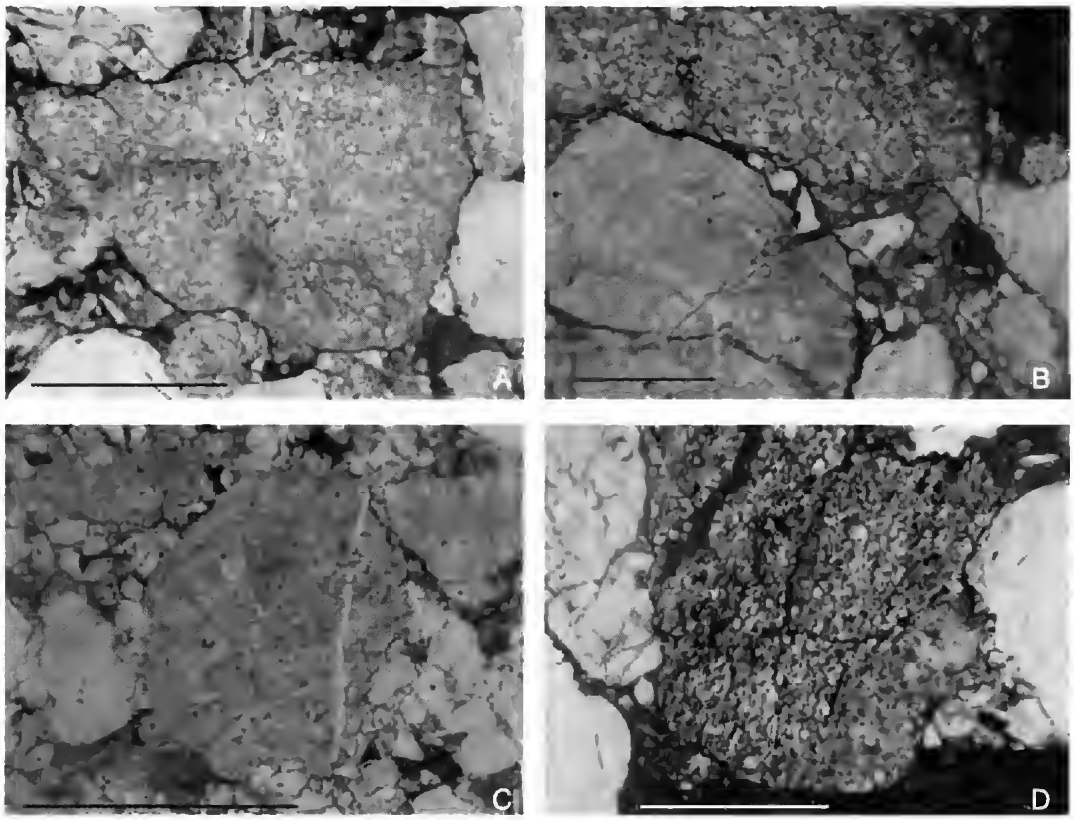

FIG. 6. — Photomicrographs showing clasts (sand sizes) of mudstones (dark) and cherts (light) in the matrix part of the chert-pebble conglomerates. These mudstone clasts contain many radiolarian tests (small round circles). **A-D**, Psammitic matrices of the chert-pebble conglomerates in the Ryoseki-Monobegawa group, East Shikoku. Scale bars: 1 mm.

Alps, Italy (Kozur & Mostler 1994). *Hozumadia reticulata* is reported from the lower Ladinian beds in the Southern Alps (Dumitrica *et al.* 1980). The species is characteristic in *Spongosilicarmiger italicus* zone of the lower Fassanian (Kozur & Mostler 1994). *Tiborella cochleata* is reported with *Triassocampe deweveri* from chert in Inuyama, Mino-Tamba Belt (Nakaseko & Nishimura 1979).

The Upper Triassic radiolarians such as *Capnodoce sarisa*, *Theocorys* sp. A, *Sarla* (?) *externa*, *Acanthocircus vigrassi* and *Corum speciosum* are extracted from chert pebbles. *Capnodoce sarisa* is described from the Upper Triassic formations in Turkey and Sicily (De Wever *et al.* 1979). This species occurs with *Theocorys* sp. A and Carnian conodonts from the gray chert in Shimo-aso of the Mino-Tamba Belt (Nakaseko & Nishimura 1979). *Sarla* (?) *externa* is reported from the upper Carnian (?)-middle Norian beds in Mid-East Oregon (Blome 1983). *Acanthocircus vigrassi* was reported from the Triassic (upper Carnian (?)-middle Norian) Cabin mudstone in East Oregon (Blome 1984). *Corum speciosum* is described from the Rail Cabin mudstone (lower-middle Norian) in Oregon (Blome 1984). *Paleosaturnalis* sp. are extracted with *Sarla* (?) *externa* from a chert pebble in the conglomerate.

Parahsuum simplum and *Gigi fustis* of the earliest Jurassic materials are also found in the other chert gravels. *Parahsuum simplum* is the index species of the *P. simplum* zone (Hori 1990). This species is widely reported from the bedded chert in Mino-Tamba, Ashio, North Chichibu and South Chichibu belts (Yao 1982; Suyari *et al.* 1982; Ishida 1983; Sashida 1988). *Gigi fustis* is reported from the calcareous chert in the lower

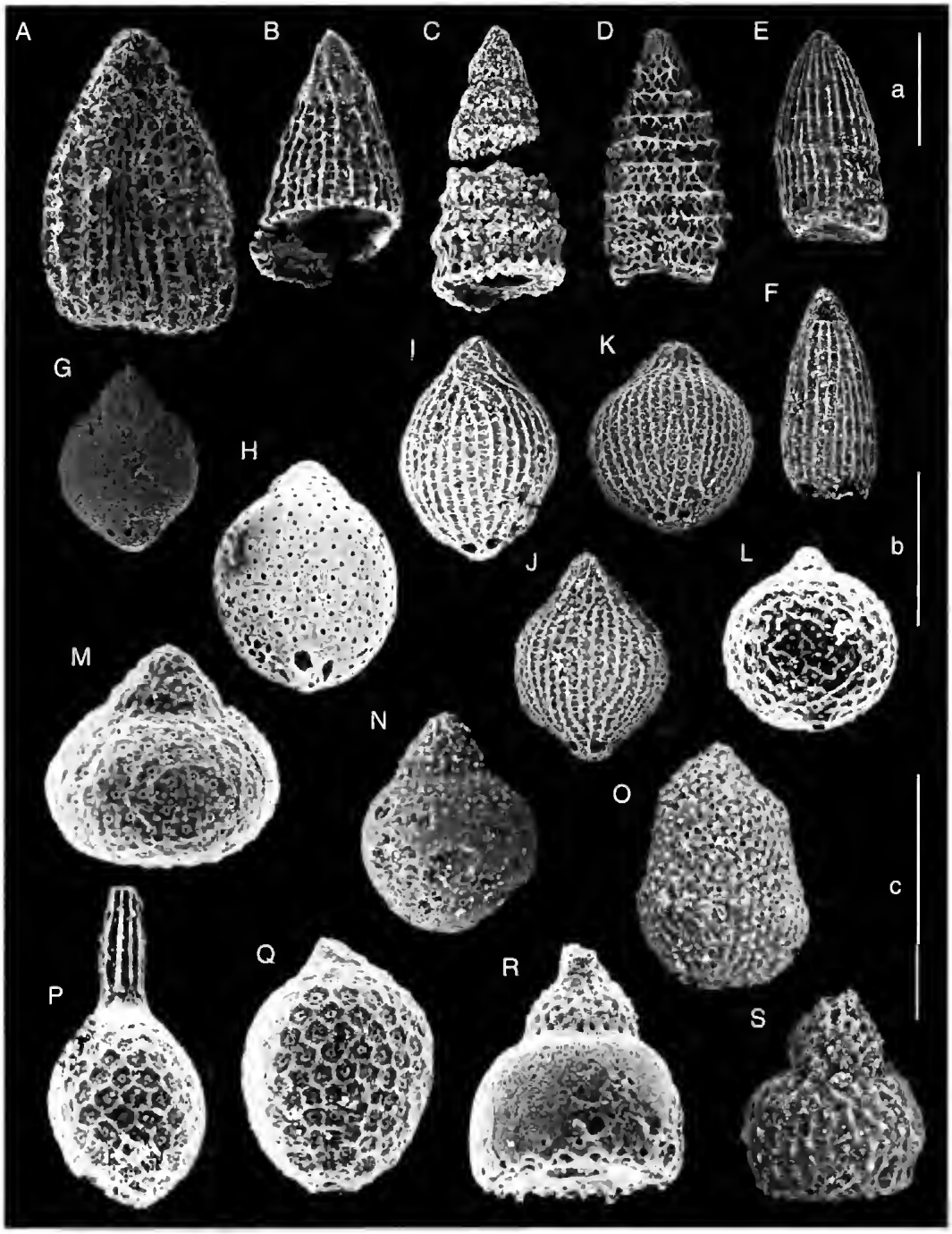

FIG. 7. — Early, Middle and Late Jurassic radiolarians from the small clasts and pebbles of mudstones in the chert-pebble conglomerates of the Ryoseki-Monobegawa group in East Shikoku. **A**, *Parahsuum ovale* Hori & Yao; **B**, *Parahsuum* (?) *grande* Hori & Yao; **C**, *Dictyomitrella kamoensis* Mizutani & Kido; **D**, *Ristola dhimenaensis* (Baumgartner); **E**, **F**, *Archaeodictyomitra suzukii* Aita; **G**, *Tricolocapsa fusiformis* Yao; **H**, *Tricolocapsa* aff. *fusiformis* Yao; **I-K**, *Tricolocapsa plicarum* Yao; **L**, *Tricolocapsa* cf. *ruesti* Tan; **M**, *Stichocapsa japonica* Yao; **N**, *Tricolocapsa* cf. *parvipora* Tan of Yao, **O**, *Theocapsomma cordis* Kocher; **P**, **Q**, *Stylocapsa oblongula* Kocher; **R**, *Eucyrtidiellum unumaensis* (Yao); **S**, *Eucyrtidiellum nodosum* Wakita. Scale bars: 100 µm; a, A, D; **b**, B, C, E-G, I-L; **c**, H, M-S.

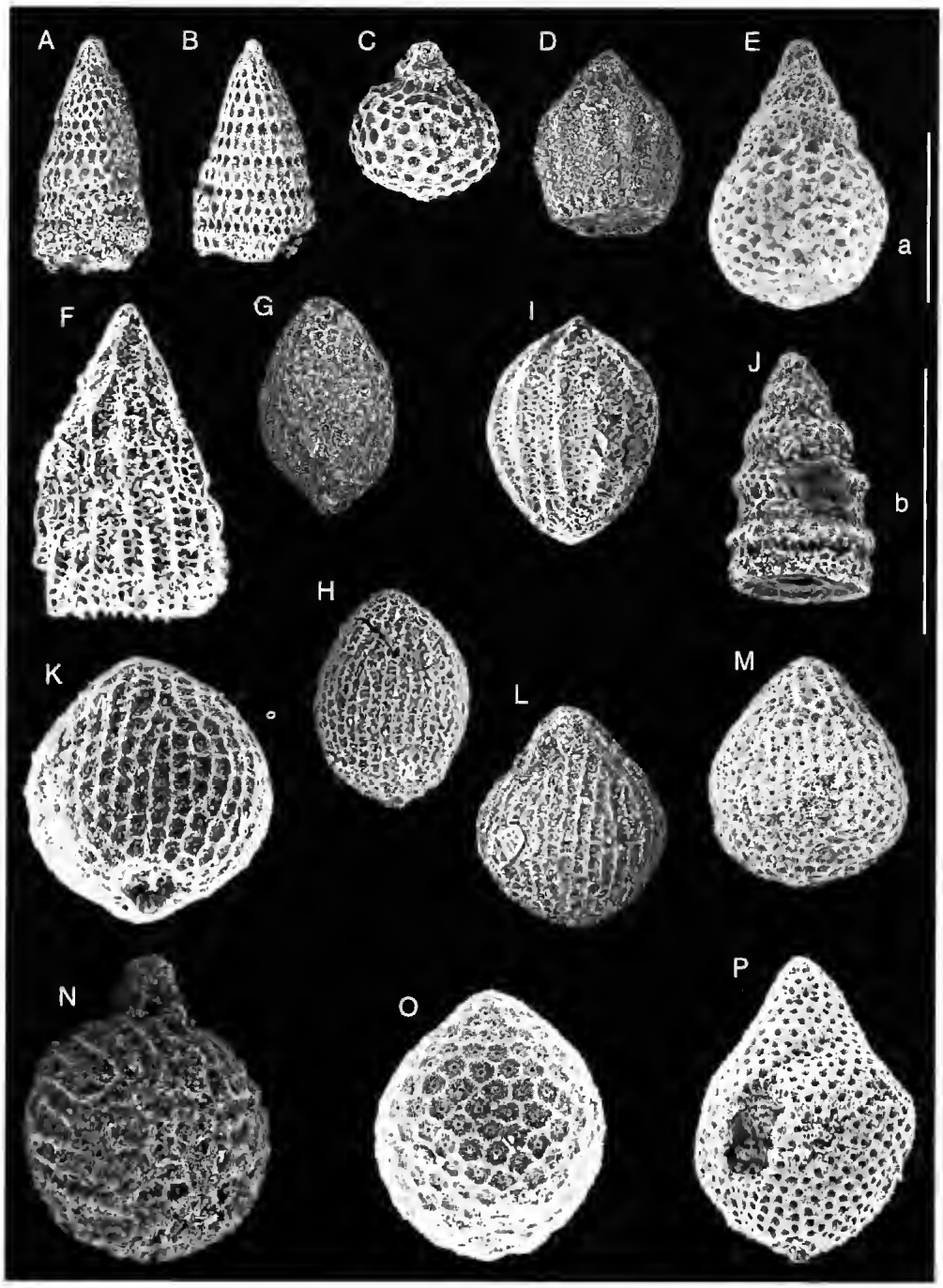

FIG. 8. — Middle-Late Jurassic and earliest Cretaceous radiolarians from the small clasts and pebbles of mudstones in the chert-pebble conglomerates of the Ryoseki-Monobegawa group in East Shikoku. **A**, **B**, *Pseudodictyomitra primitiva* Yao; **C**, *Sethocapsa pseudouterculus* Aita; **D**, *Eucyrtidiellum pyramis* (Aita); **E**, *Sethocapsa horokanaiensis* Kawabata; **F**, *Hsuum maxwelli* Pessagno; **G**, **H**, *Stichocapsa naradaniensis* Matsuoka; **I**, *Protunuma japonicus* Matsuoka & Yao; **J**, *Cinguloturris carpatica* Dumitrica; **K**, **L**, *Tricolocapsa conexa* Matsuoka; **M**, *Stylocapsa lacrimaris* Matsuoka; **N**, *Stylocapsa* (?) *spiralis* Matsuoka; **O**, *Gongylothorax favosus* Dumitrica; **P**, *Stichocapsa robsta* Matsuoka. Scale bars: 100 µm; a, A-J, L, M, P; b, K, N, O.

Liassic (Sinemurian-?Pliensbachian) *Budva* zone in the Dinarides, Montenegro (Gorican 1994). The related species co-occur with *P. simplum* from chert in the Katsuyama Section of the Mino-Tamba Belt (Hori 1990).

Matrices of the chert-pebble conglomerates contain many small clasts of mudstones as well as small clasts of cherts. Their diameters are less than 2 mm. Among these mudstone clasts, some are composed of micaceous black mudstones. The others are siliceous mudstones and tuffaceous ones that are usually dark gray or black colored. They commonly contain many radiolarians (Fig. 6). These small clasts of mudstones and some mudstone pebbles in the chert-pebble conglomerates yield the Early Jurassic, Middle-early Late Jurassic, Late Jurassic, and the earliest Cretaceous radiolarians (Figs. 7, 8). Among them, the Early Jurassic materials are *Parahsuum ovale* and *Parahsuum* (?) *grande*. *Parahsuum ovale* has its range in the *Parahsuum simplum* zone. This species is nearly the same age as *P. simplum*, but appears later in the bedded chert sequences of the Mino-Tamba Belt (Hori 1990). This species is also reported from the black mudstone of the North Chichibu Belt in Kyushu, SW Japan (Hori 1990; Miyamoto & Kuwazuru 1993). *Parahsuum* (?) *grande* is the index species of the zone that belongs to the Upper Lower Jurassic (Hori 1990). The Middle-early Late Jurassic materials are *Tricolocapsa plicarum*, *T. fusiformis*, *T.* aff. *fusiformis*, *T. conexa*, *T. parvipora*, *T.* cf. *ruesti*, *Gongylothorax favosus*, *Eucyrtidiellum unumaensis*, *E. nodosum*, *Theocapsomma cordis*, *Dictyomitrella kamoensis*, *Archaeodictyomitra* cf. *suzukii*, *Stichocapsa japonica*, *S. robusta*, *Stylocapsa oblongula*, *Hsuum maxwelli*, *Ristola dhimenaensis*. They are reported from the *Tricolocapsa plicarum* zone and *Tricolocapsa conexa* zone or *Stylocapsa* (?) *spiralis* zone of Matsuoka (1995), and/or *Tricolocapsa tetragona* interval zone (IZ; Callovian)-*Foremanella hipposidericus* zone (Oxfordian) of Aita (1987). For example, *Tricolocapsa conexa* ranges from the *Tricolocapsa tetragona* IZ to the *Foremanella hipposidericus* zone of Aita (1987). It also ranges from the *Tricolocapsa conexa* zone (upper Bathonian) to the *Stylocapsa* (?) *spiralis* zone (Oxfordian) of Matsuoka (1995). This species is regarded to indicate the UA zones 6-15 of Gorican (1994) and the UA zones 4-7 of InterRad J-C WG (1995). These zones are correlated with the late Bajocian to Bathonian or Callovian. *Tricolocapsa parvipora* has its range in the *Tricolocapsa tetragona* IZ-*Amphipyndax tsunoensis* IZ of Aita (1987). This species is regarded to indicate the UA zones 3-5 of Baumgartner (1984), and the UA zones 6-7 (InterRad J-C WG 1995) that are correlated with the late Middle-early Late Jurassic (middle Bathonian to Callovian or early Oxfordian). *Cingulotturris carpatica*, *Stylocapsa lacrimaris*, *Stylocapsa* (?) *spiralis*, *Stichocapsa naradaniensis*, *Protunuma japonicus* are characteristic of the *Stylocapsa* (?) *spiralis* zone-*Cingulotturris carpatica* zone (Lower-middle Uppet Jurassic) of Matsuoka & Yao (1985), and the *Stylocapsa* (?) *spiralis* zone-*Hsuum maxwelli* zone (uppermost Callovian-Kimmeridgian) of Matsuoka (1995). The latest Jurassic and earliest Cretaceous materials are *Pseudodictyomitra primitiva*, *Sethocapsa horokanaiensis*, *Sethocapsa pseudoturculus*, *Eucyrtidiellum pyramis*. Among them, *Pseudodictyo-mitra primitiva* is the zone index species (Matsuoka 1995). *Sethocapsa pseudoturculus* and *Eucyrtidiellum pyramis* are characteristic of the lowest Cretaceous *Ditrabs sansalvadorensis* zone (Aita 1986). According to Kawabata (1988), *Sethocapsa horokanaiensis* ranges from the *Tricolocapsa yaoi* assemblage zone (AZ) to the *Pseudodictyomitra primitiva* AZ of Matsuoka & Yao (1985). This species occurred partly with *P. primitiva* or *E. pyramis* in the chert-siliceous mudstone sequences of the Sorachi group.

Other assemblages include Early and Late Permian radiolarians such as *Pseudoalbaillella scalprata* morphotype *postscalprata*, *Follicucullus porrectus*, *F. scholasticus*, *F. charveti*, *Albaillella asymmetrica*, *A. triangularis*, *A. excelsa*, *A.* aff. *levis* and *Nazarovella* sp. (Fig. 9). According to Ishiga (1990), *Pseudoalbaillella scalprata* morphotype *postscalprata* has its range in the upper Lower Permian. *Albaillella asymmetrica* ranges from the upper Lower to lower Middle Permian. The other species have ranges in the Upper Permian *F. scholasticus* zone to the *Neoalbaillella ornithoformis* zone or the *N. optima* zone (Ishiga 1990, 1991). Among them, *Follicucullus scholasticus*, *F. porrectus* and *A. triangularis* are extracted

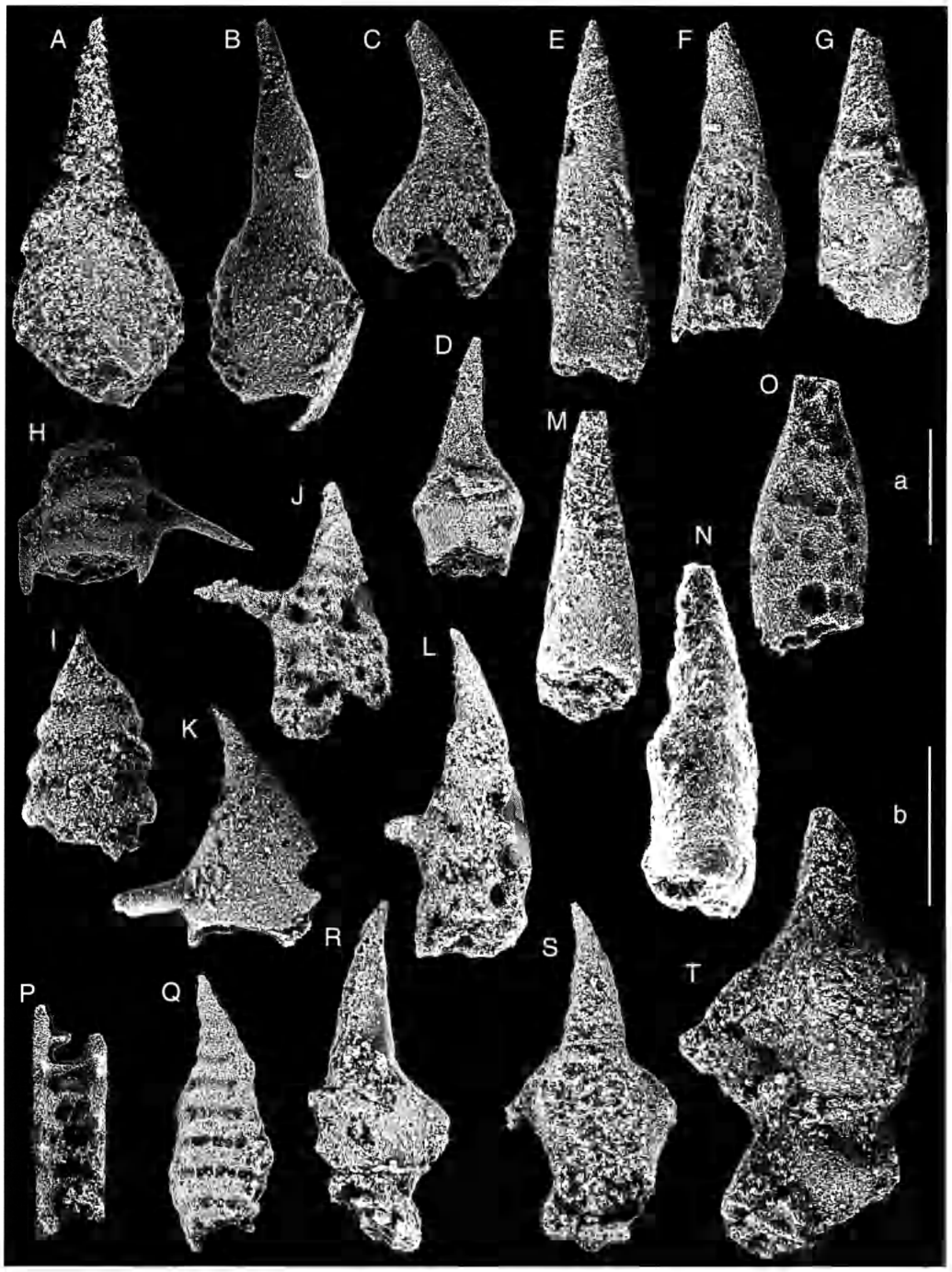

FIG. 9. — Permian radiolarians from the mudstone clasts (A-H) and chert pebbles (I-T) in the chert-pebble conglomerates of the Ryoseki-Monobegawa group in East Shikoku. **A-D**, *Follicucullus charveti* Caridroit & De Wever, every ventral spine below sinus is broken off; **E**, *Follicucullus scholasticus* Ormiston & Babcock.; **F**, **G**, *Follicucullus porrectus* Rudenko; **H-J**, *Albaillella triangularis* Ishiga, Kito & Imoto; **I**, Ventral wing-side view. Ventral wing is broken off; **K**, *Albaillella* aff. *levis* Ishiga Kito & Imoto of Kuwahara, 1997; **L**, *Albaillella excelsa* Ishiga, Kito & Imoto; **M**, *Follicucullus scholasticus* Ormiston & Babcock; **N**, **O**, *Follicucullus porrectus* Rudenko; **P**, *Nazarovella* sp.; **Q**, *Albaillella asymmetrica* Ishiga & Imoto; **R-T**, *Pseudoalbaillella scalprata* morphotype *postscalprata* Ishiga. Scale bars: 100 µm; **a**, D, F-H, N, P, Q; **b**, A-C, E, I-M, O, R-T.

from chert pebbles and mudstone clasts. *Follicucullus charveti* is only extracted from the mudstone clasts, whereas *Pseudoalbaillella scalprata* morphotype *postscalprata*, *Albaillella asymmetrica*, *A. excelsa*, *A.* aff. *levis* and *Nazarovella* sp. are extracted from the chert pebbles.

RECONSTRUCTION AND CORRELATION OF OCEANIC PLATE STRATIGRAPHY

Age determinations on chert and mudstone gravels and fine clasts of mudstones allows a reconstruction of "continuous" stratigraphy ranging from Middle Triassic to the lowest Cretaceous (Fig. 10). The succession reveals a chert-clastic sequence that is usually found in place in the Jurassic AC, with clear lithologic boundary between chert and mudstone just in the *Parahsuum simplum* zone of the Lower Jurassic (Hori 1990; Matsuoka 1995).

In the Chichibu Superterrane, Jurassic AC is distributed both in the South and North Chichibu belts (Fig. 2). They are very close to the studied formations, and have OPSs of chert-clastic sequences. Comparing the OPS of the North Chichibu Belt with the OPS of the South Chichibu Belt, the complex of the North Chichibu Belt was accreted earlier (Fig. 11). The chert facies of the North Chichibu Belt ends in the uppermost Triassic *Canoptum triassicum* zone or the lowest Jurassic *Parahsuum simplum* zone (Suyari, *et al.* 1982; Ishida 1985). On the other side, chert facies of the South Chichibu Belt continues into the Middle Jurassic *Laxtorum* (?) *jurassicum* zone-lower Upper Jurassic *Stylocapsa* (?) *spiralis* zone (Matsuoka 1984, 1996; Ishida 1985, 1987a; Hoshina *et al.* 1995; Isozaki 1997b). The OPS of origin inferred from the gravels is correlative with the OPS of the North Chichibu Belt rather than with the OPS of the South Chichibu Belt (Fig. 11).

Concerning the Permian, two types of geological columns are reconstructed. The first one is composed of chert ranging from the Lower to the Upper Permian. The second one is composed of the Upper Permian mudstone facies characterized by the occurrence of *Follicucullus charveti*. The distribution of *F. charveti* is strictly restricted among the Late Permian faunas. The fauna that includes *F. charveti* is distributed in the Upper-Permian pelitic facies of the Maizuru, Ultra-Tamba and the Kurosegawa belts (Caridroit & De Wever 1986; Ishiga 1990; Isozaki 1997a). Upper Permian mudstone-clasts are probably derived from these belts. On the contrary, Upper Permian cherts are commonly included in the Jurassic AC of the North and South Chichibu belts in the Outer Zone of SW Japan (Fig. 11). In the Inner Zone, they are common in the Jurassic AC of the Mino-Tamba Belt (e.g., Ishiga & Imoto 1980; Kuwahara 1997).

PROVENANCE OF CHERT AND MUDSTONE GRAVELS IN RYOSEKI-MONOBEGAWA GROUP

Among these radiolarian-bearing gravels and clasts, Triassic to Early Jurassic chert pebbles and Early to early Middle Jurassic mudstone clasts are probably derived from the AC of the North Chichibu Belt. On the contrary, the late Middle-Late Jurassic and earliest Cretaceous mudstone clasts are considered to be derived from the equivalents of the Torinosu group (Ishida 1994). The same species of late Middle-Late Jurassic and the earliest Cretaceous radiolarians are common in the Torinosu group. The Torinosu group is upper Middle-Upper Jurassic and lowest Cretaceous open-sea and shallow marine sediments composed of mudstone facies with small amount of sandstones, muddy limestones and conglomerates. The thickness is thinner than 250 m. The Torinosu group is now distributed in the South Chichibu Belt and the south unit of the Kurosegawa Belt where the group unconformably overlies the pre-Jurassic ACs and the Triassic shallow-marine formations (Fig. 11). On one hand, the shallow-marine Triassic formation is never distributed in the north unit of the Kurosegawa Belt nor North Chichibu Belt where the Ryoseki-Monobegawa group unconformably overlies the Permian AC directly. There are large stratigraphic and facies gaps between the Permian AC and the Lower Cretaceous paralic formations in the north unit of the Kurosegawa Belt, whereas the Lower Cretaceous Takegatani

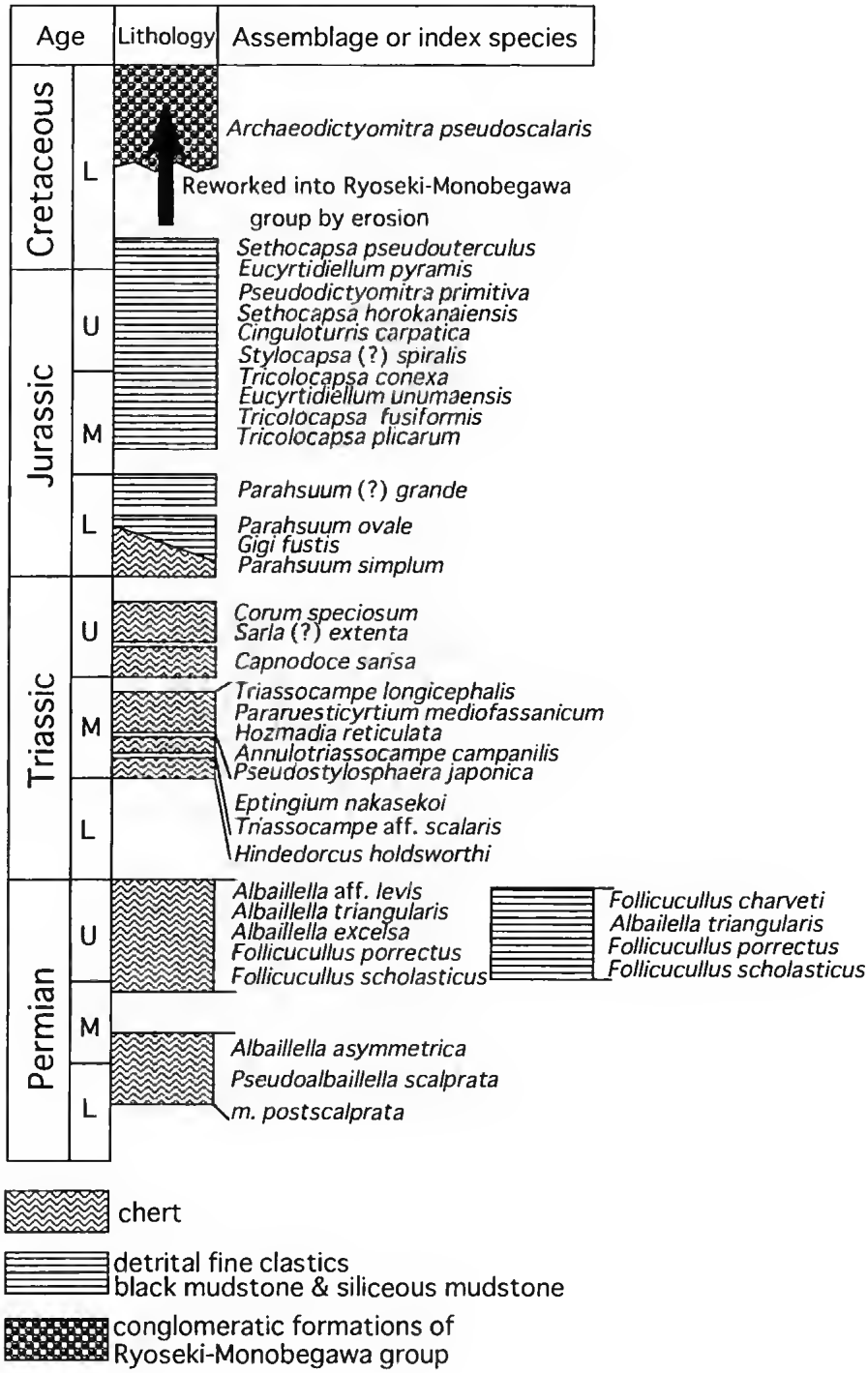

FIG. 10. — Schematic columns showing the oceanic plate stratigraphy of the provenancial terranes. They are inferred from the radiolarian-bearing chert-pebbles and mudstone-clasts in the chert-pebble conglomerates of the Ryoseki-Monobegawa group.

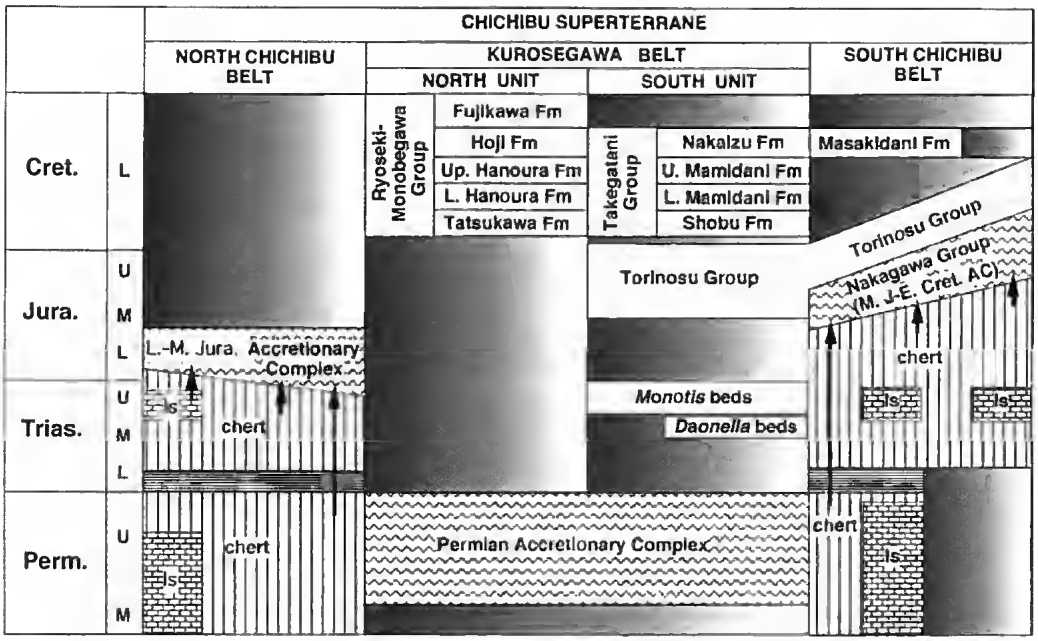

FIG. 11. — Stratigraphy of the upper Paleozoic and Mesozoic formations in the North Chichibu, South Chichibu and Kurosegawa belts in the Chichibu Superterrane, East Shikoku.

group and the Masakidani formation that are equivalent of the Ryoseki-Monobegawa group overlie the Torinosu group in the south unit of the Kurosegawa Belt and the South Chichibu Belt. There are not important stratigraphic gaps nor facial differences among the Torinosu group, Ryoseki-Monobegawa group and its equivalents (Fig. 11).

As a result, the author considers that these chert pebbles probably originated from the chert-clastic sequences and/or complexes of the North Chichibu Belt. It also indicates that the Lower to lower Middle Jurassic ACs of the North Chichibu Belt probably cropped out at the continental side of the Ryoseki-Monobegawa group, and were already eroded in the Early Cretaceous. On one hand, pebbles and small fragments of mudstones containing the Late Middle to Late Jurassic and the earliest Cretaceous radiolarians probably originated from the late Middle Jurassic-earliest Cretaceous cover formations that are the equivalent of the Torinosu group. The equivalents of the Torinosu group were spread widely above the North Chichibu Belt and they were eroded together at the same orogenic event.

PROVENANCE OF ACCOMPANIED FUSULINACEAN-LIMESTONE PEBBLES

In addition to chert pebbles, the conglomerate of the Lower Hanoura formation also contains small gravels of micritic limestones. Limestone gravels usually do not derive from long distances, as river waters usually have acidic chemical conditions. They contain Permian and Carboniferous fusulinids species of *Fusulinella*, *Neoschwagerina* and *Yabeina*. Among them, *N. craticulifera* is characteristic of these micritic limestone gravels. Large blocks of white micrites that contain species of *Neoschwagerina*, *Yabeina* and *Fusulinella* are characteristic in the Jurassic ACs of the North and South Chichibu belts, whereas the *Colania-Lepidolina* bearing muddy limestones are characteristic in the Kurosegawa Belt (Ishii 1990). It suggests that the North Chichibu and the Kurosegawa belts belong to two distinct units. It is also remarkable that the fusulinid-bearing white micrite pebbles are included in the chert-pebble conglomerates. Therefore, these micrite pebbles are probably derived from the limestone blocks of the North

Chichibu Belt. They are transported together with the radiolarian-bearing chert pebbles and mudstone clasts. Based on paleocurrent evidences (Matsukawa & Tsuneoka 1993) and facies analysis (Ishida *et al.* 1992, 1996), sediments of the Ryoseki-Monobegawa group were transported from the northwest to the southeast. The direction of transport is relevant to a potential provenance from the North Chichibu Belt.

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Lower Triassic (Spathian) radiolarians from the Kuzu area (Tochigi Prefecture, central Japan)

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ABSTRACT

A well-preserved Lower Triassic radiolarian fauna was found in a siliceous claystone and chert sequence in the Kuzu area of the Ashio Terrane, central Japan. This fauna includes "Paleozoic type" radiolarians represented by spicular type Palaeoscenidiidae and Entactiniidae with some common species of the Late Early Triassic *Parentactinia nakatsugawaensis* (Pn) Assemblage. Spathian conodonts *Neospathodus triangularis* (Bender) and *Neohindeodella benderi* (Kozur & Mostler) co-occur with these radiolarians. Based on the faunal analysis and chronological dating by conodonts, this radiolarian fauna probably reptesents an oldet patt of the Pn Assemblage, where "Paleozoic type" Entactiniidae are still a dominant component in Early Triassic time.

KEY WORDS
Ashio Terrane, conodonts, Entactiniidae, Palaeoscenidiidae, Radiolaria, Spathian, Lower Triassic.

RÉSUMÉ

Radiolaires triassiques inférieurs (Spathien) de la région de Kuzu (Préfecture de Tochigi, Japon central).

Une faune bien conservée de radiolaires du Trias inférieur a été trouvée dans une série de pélites siliceuses et de jaspes dans la tégion de Kuzu, Ashio Terrane, Japon centtal. Cette faune inclut des tadiolaites de « type paléozoïque » représentés par des spicules de type Palaeoscenidiidae et Entactiniidae avec quelques espèces communes de l'Assemblage à *Parentactinia nakatsugawaensis* (Pn) de la fin du Trias inférieur. Des conodontes spathiens *Neospathodus triangularis* (Bender) et *Neohindeodella benderi* (Kozur & Mostler) co-existent avec ces radiolaires. Sur la base des faunes analysées et de la datation par les conodontes, cette faune de radiolaires représente probablement une partie ancienne de l'assemblage à *P. nakatsugawaensis*, dans lequel les Entactiniidae de « type Paléozoique » sont encore dominants au Trias inférieur.

MOTS CLÉS
Terrane d'Ashio, conodontes, Entactiniidae, Palaeoscenidiidae, Radiolaria, Spathien, Trias inférieur.

INTRODUCTION

Since radiolarian extraction by the HF method was established, the biostratigraphy and taxonomy of Triassic radiolarians has developed rapidly mainly in the European Tethys (e.g., Kozur & Mostler 1972; Dumitrica 1978a, b; De Wever *et al.* 1979), western North America (e.g., Pessagno *et al.* 1979; Blome 1984), and western Pacific regions (e.g., Nakaseko & Nishimura 1979; Yao 1982). Due to the scarcity of radiolarian-bearing Lower Triassic sequences around the world, Lower Triassic radiolarian biostratigraphy lags well behind that of the Middle Triassic to Jurassic (e.g., Matsuoka & Yao 1986; Hori 1988, 1990; Matsuoka 1995a, b; Sugiyama 1997). Lithological and geochemical investigations have recently been undertaken in Upper Permian and Lower Triassic sequences involving the Permian-Triassic (P-T) boundary in various areas in Japan (Yamakita 1987; Ishida *et al.* 1992; Kuwahara *et al.* 1991; Sugiyama 1992; Kamata & Kajiwara 1996). Only limited information is available on the biostratigraphy of Lower Triassic radiolarians (Sashida 1983, 1991; Sashida & Igo 1992; Sugiyama 1992, 1997; Blome & Reed 1992; Nagai & Mizutani 1993; Kozur *et al.* 1996). Biostratigraphic and taxonomic investigations are important to establish the transition between the Paleozoic and Mesozoic radiolarian faunas. Accordingly, this paper presents results of a detailed investigation of Lower Triassic radiolarians in the Kuzu area of the Ashio Terrane, Tochigi Prefecture. In a preliminary report, Kamata (1995) described Lower Triassic radiolarian biostratigraphy from a section belonging to the Kuzu Complex. In this paper, the systematics of Lower Triassic radiolarians from two samples in the same section are presented.

GEOLOGIC SETTING

Lower Triassic radiolarians were obtained from a

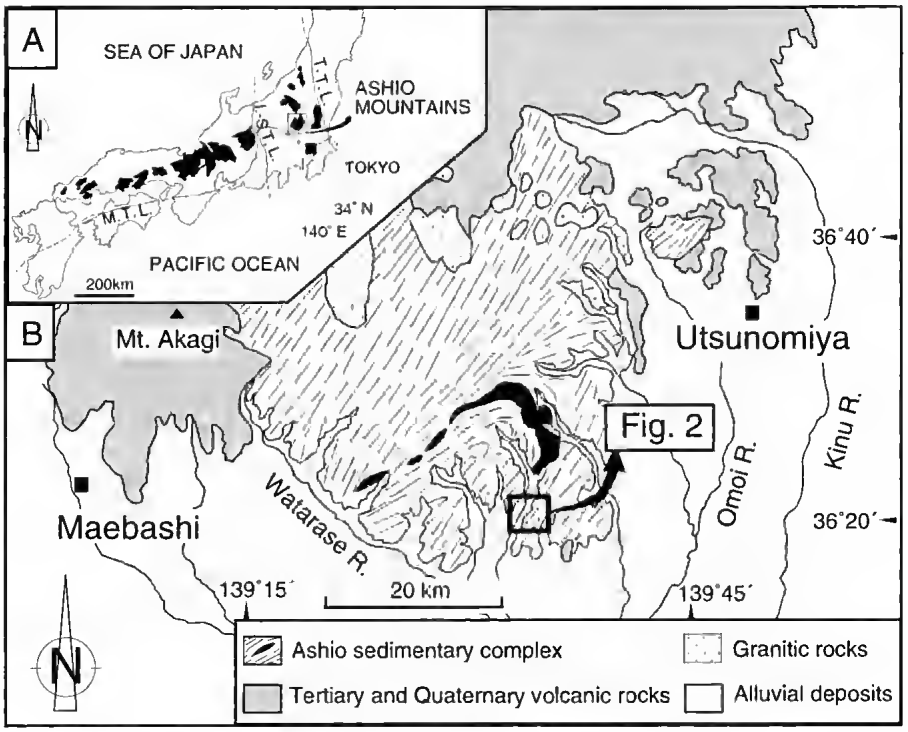

FIG. 1. — Index map showing **A**, the distribution of Inner Zone of southwest Japan; **B**, the outline of geology of the Ashio Mountains; **M.T.L.**, Median Tectonic Line; **I.-S.T.L.**, Itoigawa-Shizuoka Tectonic Line; **T.T.L.**, Tanakura Tectonic Line.

siliceous claystone and bedded chert sequence of the Kuzu Complex (Kamata 1996) in the Ashio Terrane (Fig. 1). The Kuzu Complex consists mainly of stacked slices of a chert-clastic sequence with huge thrust sheets of greenstone and limestone. The chert-clastic sequence is formed of Lower Triassic black carbonaceous or siliceous claystone, Middle Triassic to Lower Middle Jurassic chert, and Middle to Lower Upper Jurassic clastic rocks (Kamata 1996, 1997). The investigated section, belonging to the lower part of this complex, is located at the southeastern part of Tanuma Town, Aso-Gun, Tochigi Prefecture (Fig. 2). It is exposed along a road-cut of the Natural Laboratory of Tokyo University of Agriculture and Technology. The section is composed of alternating black siliceous claystone and dark gray chert with pale green siliceous claystone interbeds. The occurrence of representative species of the *Parentactinia nakatsugawaensis* (Pn) Assemblage of Sugiyama (1992) were reported from this section previously (Kamata 1995). The tentative stratigraphy of this section is established in ascending order as follows (Figs 3, 4):

Unit A. Strongly sheared sandstone, approximately 2 m thick.

Unit B. Gray, medium-grained sandstone including blocks of bedded chert yielding Upper Triassic radiolarians, about 8 m thick.

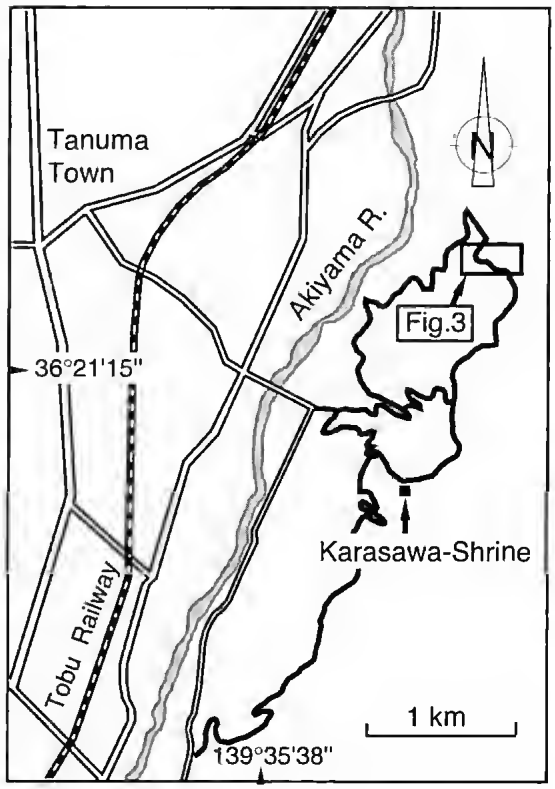

FIG. 2. — Locality map showing the location of the study section.

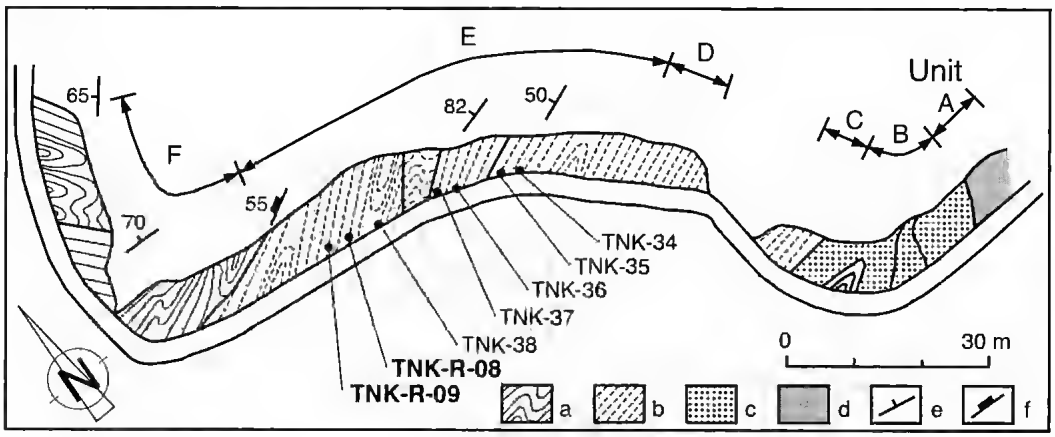

FIG. 3. — Route map along the road-cut of the Natural Laboratory of Tokyo Institute of Agriculture and Technology showing the occurrence of siliceous rocks and radiolarian localities. **a**, gray bedded chert; **b**, greenish gray siliceous claystone intercalated with black siliceous claystone and black chert; **c**, sandstone; **d**, sheared zone; **e**, strike and dip of bedding plane; **f**, strike and dip of fault plane.

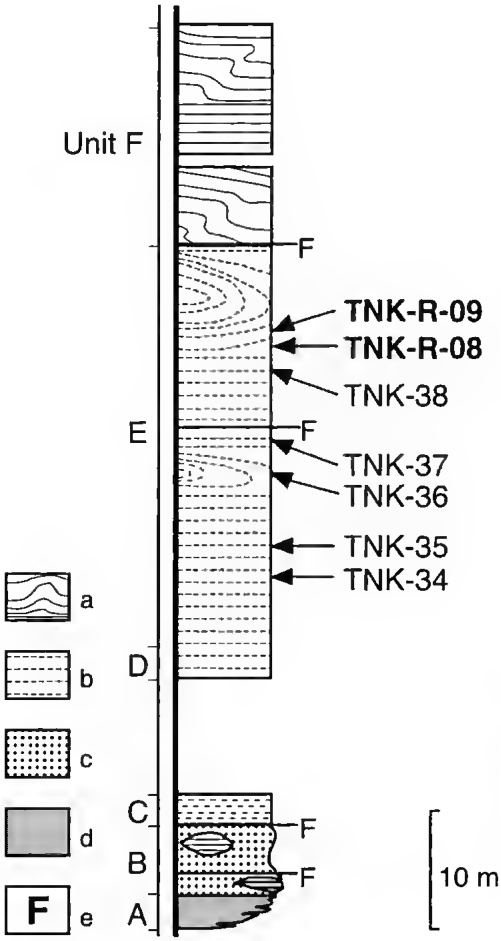

FIG. 4. — Columnar section of the study section. **a**, bedded chert; **b**, siliceous claystone with layer of chert; **c**, sandstone; **d**, sheared zone; **e**, fault.

Units C, D. Both units composed of pale green, fissile, siliceous claystone; well-developed scaly cleavages developed subparallel to bedding plane.
Unit E. Unit composed mainly of pale green claystone with intercalations of black siliceous and/or gray to black chert layers a few centimeters thick. The black siliceous claystone is rather muddy compared with the chert, and more siliceous than the pale green siliceous claystone. The black siliceous claystone is similar to the muddy chert of Sugiyama (1992). Thickness and amount of the black siliceous claystone and chert layers increases upwards in the unit; siliceous claystone and chert layers alternate in the upper part. Minor folding is present. Alternating black siliceous claystone (TNK-R-08) and black chert (TNK-R-09) from the upper part of Unit E contain Spathian radiolarians and conodonts. Radiolarian fauna from samples TNK-34 to 38 described by Kamata (1995) is also of Spathian age.
Unit F. Well-bedded gray to black chert containing Middle Triassic radiolarians of the *Triassocampe deweveri* Assemblage of Yao (1982).

GEOLOGIC AGE AND RADIOLARIAN FAUNA

Sample TNK-R-09 contains a radiolarian fauna comparable to the *Parentactinia nakatsugawaensis* Assemblage of Sugiyama (1992) and also a rich conodont fauna composed of *Neospathodus triangularis* (Bender 1970), *N. clinatus* Orchard & Sweet, 1995, *Cornudina igoi* Koike, 1996, *Neohindeodella benderi* (Kozur & Mostler, 1970), and many unidentified ramiform elements (Fig. 5). No age-diagnostic conodonts are present in sample TNK-R-08 which contains very well-preserved radiolarians.
Neospathodus triangularis (Bender, 1970) and *Neohindeodella benderi* (Kozur & Mostler, 1970) are well-known Late Early Triassic conodont species (Fig. 6). The occurrence of *Neospathodus triangularis* (Bender, 1970) has been reported from the Spathian of the Tethyan region in Kashmir, the Salt Range, Spiti, and Japan (e.g., Sweet *et al.* 1971; Goel 1977; Koike 1981; Matsuda 1985). Matsuda (1985) and Sweet (1988) summarized the conodont zonations and indicated ranges of Lower Triassic conodonts based on these biostratigraphic investigations. In these regions, *N. triangularis* is one of the main components of the Spathian conodont fauna. The base of the *N. triangularis-N. hormeri* zone (Matsuda 1985) and *N. triangularis* zone (Sweet 1988), both indicative of the lower Spathian, are defined by the first occurrence of this species. In Japan, *N. triangularis* is a characteristic species of the *N. triangularis-N.* ? *collinsoni* zone of the lower Spathian (Koike 1981). Furthermore, Koike (1996) described *Cornudina igoi* from the Taho Formation distributed in Ehime Prefecture south-

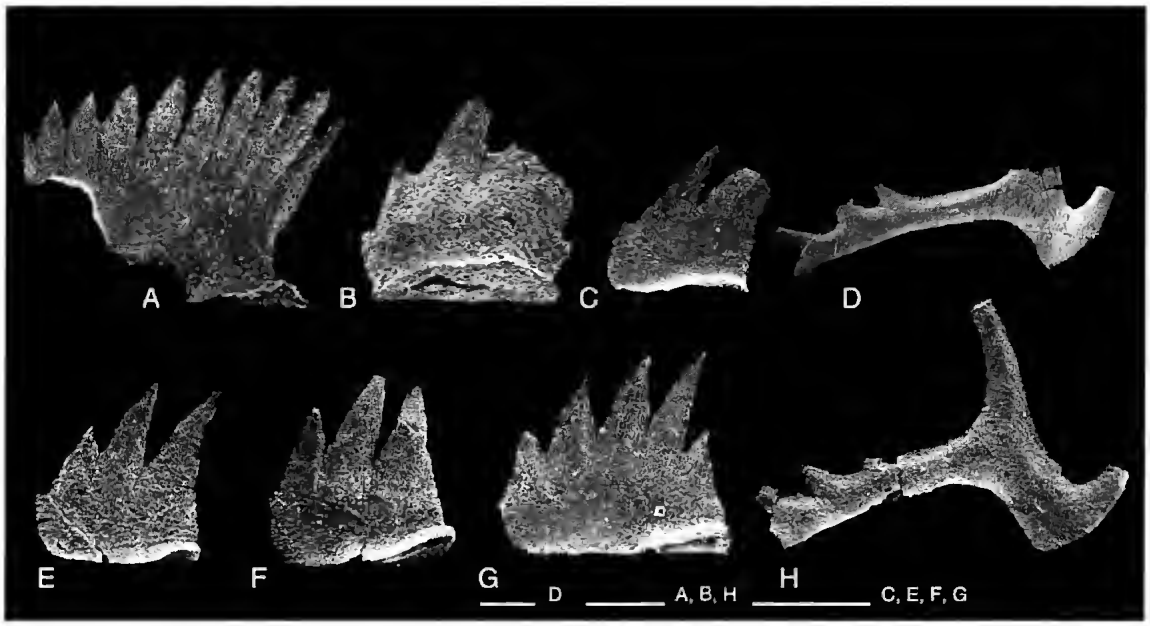

FIG. 5. — Spathian conodonts from the TNK-R-09. **A**, *Neospathodus triangularis* (Bender), **B**, **C**, *Cornudina igoi* Koike; **D**, **H**, *Neohindeodella benderi* (Kozur & Mostler); **E**, **F**, *Neospathodus* sp.; **G**, ? *Neospathodus clinatus* Orchard & Sweet. Scale bars: 100 µm.

west Japan, and indicated that this species occurs in the basal part of the *N. triangularis-N. hormeri* zone of the lower Spathian (Fig. 6).

The radiolarian fauna in this paper consists mainly of Palaeoscenidiidae and Entactiniidae with some common species of the Pn Assemblage of Sugiyama (1992) and TR1 zone of Sugiyama (1997). The fauna is represented by species of *Archaeosemantis*, *Parentactinia*, *Entactinia* (?), *Entactinosphaera* (?), *Cryptostephanidium*, and *Pantanellium* (?) (Fig. 7). Tripod or mono-segmented Nassellarians, such as *Hozmadia* and multi-segment Nassellaria such as *Triassocampe* rarely occur.

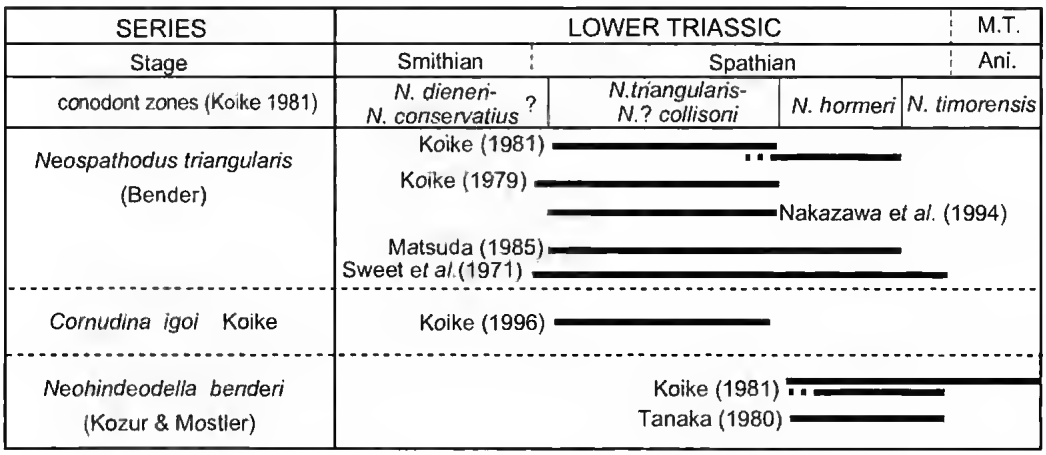

FIG. 6. — Known ranges of detected conodont species plotted on the conodont zones proposed by Koike (1981).

species \ sample number	TNK-34	TNK-35	TNK-36	TNK-37	TNK-38	TNK-R-08	TNK-R-09
Lithology	s.c.	ch.	s.c.	ch.	ch.	s.c.	ch.
Archaeosemantis brevispinosa Kamata	–	–	–	–	–	+	–
Archaeosemantis cristianensis Dumitrica	+	+	–	–	–	+	+
Archaeosemantis sp.	+	+	+	–	–	+	+
Archaeothamnulus sp.	+	+	+	–	–	+	–
Parentactinia karasawayamaensis Kamata	–	–	–	–	–	+	–
Parentactinia nakatsugawaensis Sashida	+	–	+	+	+	+	+
Parentactinia sp. A	–	–	–	–	–	+	–
Parentactinia okuchichibuensis (Sashida)	–	–	–	–	–	+	–
Parentactinia sp.	+	+	+	–	–	+	+
Protopsium sp.	+	+	+	–	+	–	+
Plafkerium sp.	–	–	–	+	–	–	–
Pantanellium (?) *virgeum* Sashida	+	–	–	–	–	+	–
Pantanellium (?) sp. A	–	–	–	–	–	+	–
Pantanellium (?) sp.	+	+	+	+	+	+	+
Tiborella agria Sugiyama	–	–	–	+	–	–	–
Hozmadia cf. *ozawai* Sugiyama	–	+	–	–	–	+	–
Hozmadia sp.	–	+	+	+	–	+	+
Cryptostephanidium longispinosum (Sashida)	–	+	+	+	–	+	–
Cryptostephanidium sp.	–	–	+	+	–	+	–
Oertlispongus sp.	–	+	–	–	–	+	–
Triassobipedis (?) sp.	–	+	+	+	–	–	–
Zevius (?) sp.	–	+	–	–	–	+	–
Entactinia (?) *tanumaensis* Kamata	–	–	–	–	–	+	–
Entactinia nikomi Sashida and Igo	–	–	+	–	–	–	–
Polyentactinia (?) *crux* Sugiyama	–	–	–	–	–	+	–
Polyentactinia furutanii Sugiyama	–	–	–	–	–	+	–
Polyentactinia sp.	–	–	–	–	–	+	–
Entactinosphaera (?) *sashidai* Kamata	–	–	–	–	–	+	–
Entactinosphaera chiakensis Sashida and Igo	–	–	–	–	–	+	–
Entactinosphaera sp.	–	+	–	–	–	+	+
Thaisphaera (?) *Igoi* Kamata	–	–	–	–	–	+	–
Entactiniidae gen. et sp. indet.	+	+	+	+	–	+	–

FIG. 7. — List of Early Triassic radiolarians from the study section. **s.c.**, siliceous claystone; **ch.**, chert.

Sugiyama (1992) considered the age of Pn Assemblage as late Spathian based on co-occurring conodonts belonging to the *Neospathodus hormeri* Assemblage but stated that the lower limit of this assemblage is unknown. Recently, Sugiyama (1997) compared TR0 and TR1 with the lower part and the upper part of the Pn Assemblage of Sugiyama (1992), respectively. In this study, *N. triangularis* (Bender, 1970) and *Cornudina igoi* Koike, 1996 are associated with some common radiolarian species of the Pn Assemblage. Kusunoki & Imoto (1996) also reported a radiolarian fauna attributed to the Pn Assemblage associated with the lower Spathian conodonts *N. triangularis* and *Gondolella jubata* (Sweet, 1970). They emphasized that the Pn Assemblage ranges down to the lower Spathian. This present evidence suggests that the range of some species of the Pn Assemblage may extend down to the lower Spathian.

As briefly stated above, the radiolarian fauna discussed here has both Paleozoic and Lower Triassic affinities. The family Entactiniidae is particularly abundant exceeding more than 50% of the total number of the identified radiolarian species within this fauna. Considering the range of the conodonts, the radiolarian fauna represents an older part of the Pn Assemblage (Sugiyama 1992) and

TR0 (Sugiyama 1997), and "Paleozoic type" Entactiniidae are still a dominant component in Early Triassic assemblages. Futher analysis of Spathian radiolarian faunas is necessary because *Follicuculus*, a representative species of TR0, has not been found in the studied section.

METHODS AND TECHNIQUES

Radiolarian specimens were separated from siliceous rock samples in the following manner: (1) rock samples were crushed into small fragments of several centimeters; (2) crushed samples were placed in five percent hydrofluoric acid for 24 hours; (3) samples were washed and sieved using a mesh of 50 µm opening, the residue was dried in an oven. Well-preserved radiolarian specimens were mounted on an SEM plug and gold coated in a vacuum evaporator. The surface features and inner structures were observed with the Scanning Electron Microscope.

SYSTEMATIC PALEONTOLOGY

All figured specimens are deposited in collections of the Department of Earth Sciences, University of Yamaguchi (DEUY).

Subclass RADIOLARIA Müller, 1858
Order POLYCYSTINA Ehrenberg, 1838
emend. Riedel, 1967
Suborder SPUMELLARIA Ehrenberg, 1875
Family PALAEOSCENIDIIDAE Riedel, 1967
emend. Holdsworth, 1977
Genus *Archaeosemantis* Dumitrica, 1978b

Archaeosemantis brevispinosa n. sp.
(Fig. 8A-C)

TYPES. — Holotype, Figure 8A, TNK-R-08, DEUY-YK3617; paratypes, Figure 8B, TNK-R-08, DEUY-YK3627, Figure 8C, DEUY-YK3618.

ETYMOLOGY. — *Brevispinosa* means having short spines.

OCCURRENCE. — Sample TNK-R-08, Kuzu area, central Japan.

DIMENSIONS (µm). — Based on eight specimens: length of apical spines 5.0 to 21.8 (average 15.9); length of basal spines 72.8 to 126.0 (average 85.3).

DESCRIPTION
Species composed usually of eight spines consisting of four apical spines and four basal spines, arising from a short median bar (MB). The four basal spines are conical, short, rod-like, and rugged. Two, commonly straight basal spines diverge from one end of MB. Three or four apical spines; spines conical, very short, and obliquely divergent upward from end of MB at a smaller angle.

REMARKS
Compared with other *Archaeosemantis*, the basal and apical spines of this species are shorter. *Archaeosemantis cristianensis* is similar to this species, but differs by possessing long and downwardly curved basal spines.

Archaeosemantis cristianensis
Dumitrica, 1982
(Fig 8D, H)

Archaeosemantis pterostephanus Dumitrica (part) 1978b: 52, pl. 5, figs 7, 8 (non pl. 5, figs 9-12).
Archaeosemantis cristianensis Dumitrica, 1982: 423, pl. 1, fig. 11, pl. 3, fig. 11, pl. 4, figs 5, 7, 11, pl. 6, fig. 2, pl. 7, figs 3, 12, 13. – Ando *et al.* 1991, pl. 9, fig. 12. – Nagai & Mizutani 1993: 7, pl. 1, fig. 9.
Archaeosemantis venusta Sashida, 1983: 171, pl. 36, figs 1-9; 1991: 686, fig. 5-4, 5, 6, 7, 8. – Nagai & Mizutani 1993: 7, pls 1, 11.
Archaeosemantis sp. aff. *A. venusta* Sashida, 1991: 686, figs 5-9. – Kamata 1995: fig. 6-1, 2.
Archaeosemantis sp. – Sashida 1991: 686, fig. 5-1, 2, 3.
Archaeosemantis cristianensis Dumitrica, 1982 morphotype A Sugiyama, 1992: 1209, fig. 14-3.
Archaeosemantis cristianensis Dumitrica, 1982 morphotype B Sugiyama, 1992: 1209, fig. 14-6.

OCCURRENCE. — Common in TNK-R-08, 09, Kuzu area, Tochigi Prefecture. Mt. Kinkazan and Minokamo City, Gifu Prefecture. Kanto Mountains, Saitama Prefecture, central Japan. Vicentinian Alps, Italy.

REMARKS
Dumitrica (1982) described specimens of *A. cristianensis* having broad variation in the disposi-

tion and length of spines. Sugiyama (1992) proposed two morphorypes A and B for this species, and stated that phenotypic variation is caused by the rotation of half of morphotype A around the axis of the median bar (MB).

Genus *Parentactinia* Dumitrica, 1978b
Parentactinia karasawayamaensis n. sp.
(Fig. 9G-M)

TYPES. — Holotype, Figure 9H, TNK-R-08, DEUY-YK3495; Paratypes, Figure 9G, TNK-R-08, DEUY-YK3654; Figure 9I, TNK-R-08, DEUY-YK3653; Figure 9J, TNK-R-08, DEUY-YK3650; Figure 9 K, TNK-R-08, DEUY-YK3635; Figure 9L, TNK-R-08, DEUY-YK3657; Figure 9M, TNK-R-08, DEUY-YK3533.

ETYMOLOGY. — Species name *karasawayamaensis* comes from Karasawayama Shrine close to the studied section.

OCCURRENCE. — Abundant in TNK-R-08, Kuzu area, central Japan.

DIMENSIONS (μm). — Based on ten specimens: shell diameter, 160 to 190 (average 178); length of apical or basal spines 100 to 220 (average 175); all spines broken, see Fig. 9L; wall thickness less than 10.

DESCRIPTION
Species with spherical latticed shell and a spicule consisting of seven or eight rod-like spines arising from a short eccentric MB. Rod-like spines straight and penetrating the wall of shell. Cortical shell, thin, and relatively smooth surfaced, enclosing an eccentric spicule with seven or eight radial spines and a very short MB. Cortical shell nearly spherical and supported by all radial spines. Pore pattern of shell composed of intersections of bars forming numerous quadrangular or triangular pore frames. Main radial spines long, rod-like, and occasionally curved upward outside of shell. Internal spines arise from MB and penetrate the shell wall. Main spines slightly thicker outside shell wall than in the internal portion. Four apical spines situated in the upper hemisphere diverge upwardly at about 45° above the horizontal plane. Commonly three or four basal spines. MB is eccentrical.

REMARKS
This new species is similar to *Polyentactinia* (?) *phatthalungensis*, reported by Sashida & Igo (1992), but the latter has an uneven shell wall formed of intersecting bars.

Parentactinia nakatsugawaensis
Sashida, 1983
(Figs 8E-G, I-N, 9A)

Unnamed Spumellaria – Matsuda & Isozaki 1982: pl. 3, figs 33-35;
Parentactinia nakatsugawaensis Sashida, 1983: 172-173, pl. 37, figs 1-9; 1991: 687, fig. 5-15, 16, figs 6-1, 3-6. – Sugiyama 1992: 1212, fig. 14-7-10. – Blome & Reed 1992: 376, fig. 14-3, 4. – Nagai & Mizutani 1993: pl. 1, figs 1-6. – Kamata 1995: fig. 6-4, not 8. – Kusunoki & Imoto 1996: 91, fig. 1. – Sugiyama 1997: 184, fig. 27-2, 3.
Parentactinia virgata Sashida, 1991: 689, fig. 7.

OCCURRENCE. — Abundant in TNK-R-08, 09, Kuzu area, Tochigi Prefecture. Mt. Kinkazan and Minokamo City, Gifu Prefecture. Southern Kameoka City, Kyoto Prefecture. Kanto Mountains, Saitama Prefecture, central Japan. Oregon, USA.

DIMENSIONS (μm). — Based on forty-three specimens: length of apical spines 21 to 65 (average 42); length of basal spines 65 to 234 (average 106); diameter of incomplete shells 120 to 230 (average 136).

REMARKS
This species consists of four apical and four basal spines with a loose latticed shell. The basal spines of some specimens have stout, slightly curved, long branches. Four or five branches diverge medially to distally along the basal spines. Two shorter branches are conical and diverge upward. Two additional long stout, rod-like branches diverge inward. Diameter of branches slightly smaller less that of basal spines. Each long branch bears two to four directional spinules distally. The spinules anastomose with each other forming a loosely reticulate shell. Some specimens possess an almost complete single shell. Surface of the shell rugged due to minute spinules; pores irregular in shape. Shell is supported by the basal spines and is incomplete apically. MB eccentrically situated or tangent to the shell.
Parentactinia nakatsugawaensis was first described by Sashida (1983) from black chert of the Kanto

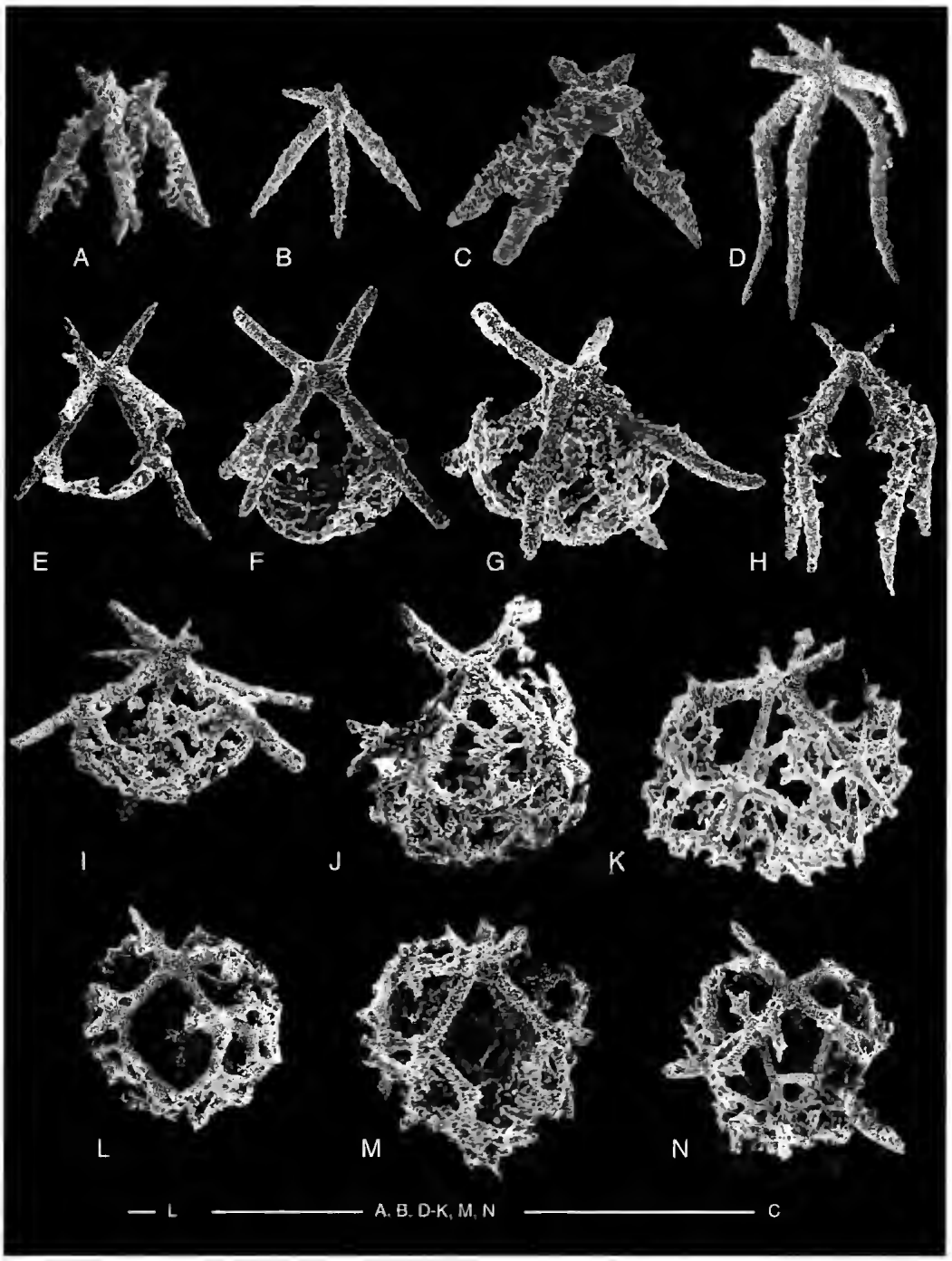

FIG. 8. — **A-C**, *Archaeosemantis brevispinosa* Kamata n. sp., **A**, holotype, DEUY-YK3617; **B**, paratype, DEUY-YK3627; **C**, paratype, DEUY-YK3618; **D**, **H**, *A. cristianensis* Dumitrica; **D**, DEUY-YK3629, **H**, DEUY-YK3481; **E-G**, **I-N**, *Parentactinia nakatsugawaensis* Sashida; **E**, DEUY-YK3538; **F**, DEUY-YK3479; **G**, DEUY-YK3545; **I**, DEUY-YK3509; **J**, DEUY-YK3603; **K**, DEUY-YK3486; **L**, DEUY-YK3506; **M**, DEUY-YK3588; **N**, DEUY-YK3422. Scale bars: 100 µm.

Mountains; later Sugiyama (1992) described this species in greater detail and considered it diagnostic of the Pn Assemblage of the upper Lower Triassic. The shell of this species is well preserved and shows variations in development in my material.

Parentactinia sp. A
(Fig. 9B)

FIGURED SPECIMEN. — Figure 9B, TNK-R-08, DEUY-YK3609.

OCCURRENCE. — Rare in TNK-R-08, Kuzu area, central Japan.

DIMENSIONS (µm). — Based on two specimens: length of long apical spines 100 to 160 (average 129): length of short apical spines less than 20; diameter of incomplete shells 140 to 175 (average 157); width of basal hemisphere approximately 350.

REMARKS
This species is composed of four apical and four basal spines with an incomplete latticed shell. Basal spines very long, thick, rod-like, slightly curved upward, and gently tapered distally. Loose hemispheric shell is supported by the four basal spines.
Parentactinia sp. A is easily distinguished from *P. nakatsugawaensis* by possessing very thick basal and apical spines.

Parentactinia okuchichibuensis
(Sashida, 1991)
(Fig. 9C)

Archaeothamnulus okuchichibuensis Sashida, 1991: 687, fig. 5-10-14.
Parentactinia okuchichibuensis (Sashida) – Sugiyama 1992: 1213, fig. 16-2a, 2b. – Nagai & Mizutani 1993: pl. 1, figs 7, 8. – Kusunoki & Imoto 1996: 91, fig. 2.

OCCURRENCE. — Common in TNK-R-08, 09, Kuzu area, Tochigi Prefecture. Mt. Kinkazan and Minokamo City, Gifu Prefecture. Southern Kameoka City, Kyoto Prefecture. Kanto Mountains, Saitama Prefecture, central Japan.

REMARKS
Sugiyama (1992) transferred this species from *Archaeothamnulus* to *Parentactinia* because it possesses two apical spines. In my material, this species also has two apical spines.

Family ENTACTINIIDAE Riedel, 1967
Genus *Entactinia* Foreman, 1963
Entactinia (?) *tanumaensis* n. sp.
(Fig. 9D-F)

TYPES. — Holotype, Figure 9D, TNK-R-08, DEUY-YK3500; paratypes, Figure 9E, TNK-R-08, DEUY-YK3522; Figure 9F, TNK-R-08, DEUY-YK3643.

ETYMOLOGY. — *Tanumaensis* is derived from Tanuma Town. Studied section is located at the southeastern part of Tanuma Town.

OCCURRENCE. — Common in TNK-R-08, Kuzu area, central Japan.

DIMENSIONS (µm). — Based on five specimens: length of main spines 50 to 110 (average 78.7): diameter of shell 80 to 100 (average 90).

DESCRIPTION
Species with a well-developed latticed shell with five to six rod-like main spines and numerous bi-spines. Latticed shell spherical with five to six needle-like primary spines. Primary spines possess shallow grooves proximally and strongly taper distally. Spine length nearly equal to diameter of shell. Shell wall rather thick, penetrated by variably-sized rounded pores. Numerous radial and very short bi-spines arise from the shell wall. Internal construction unknown.

REMARKS
This species is similar to *Entactinia nikorni* Sashida & Igo (1992), but differs from the later by possessing strongly tapered needle-like primary spines. This species is questionably assigned to *Entactinia* because of the absence of three-bladed spines.

Genus *Entactinosphaera* Foreman, 1963

Entactinosphaera (?) *sashidai* n. sp.
(Fig. 10A-D)

TYPES. — Holotype, Figure 10A, TNK-R-08, DEUY-YK3483; paratypes, Figure 10B, TNK-R-08, DEUY-YK3490; Figure 10C, TNK-R-08, DEUY-YK3508, Figure 10E, TNK-R-08, DEUY-YK3434.

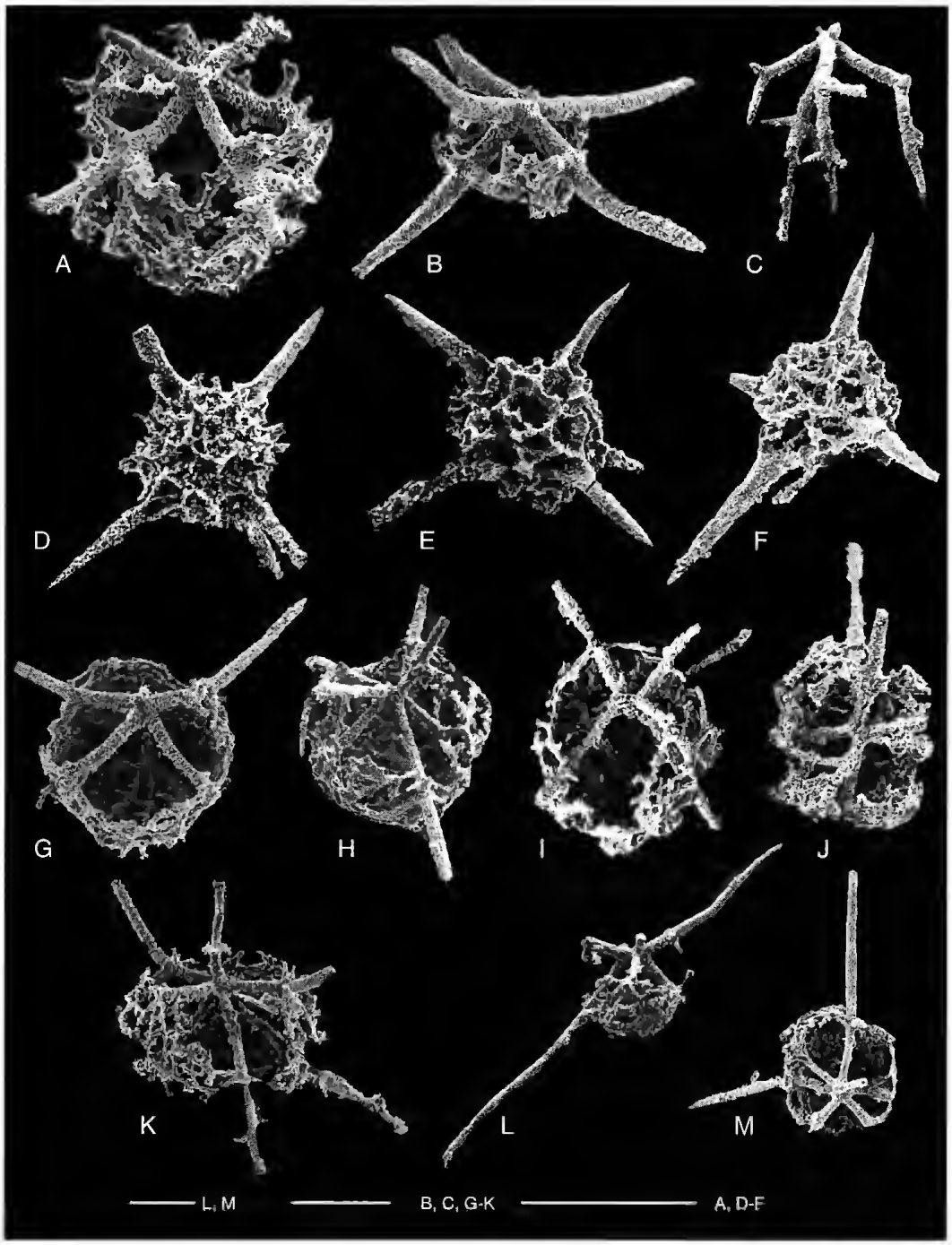

FIG. 9. — **A**, *Parentactinia nakatsugawaensis* Sashida, DEUY-YK3593; **B**, *Parentactinia* sp. A, DEUY-YK3609; **C**, *Parentactinia okuchichibuensis* (Sashida), DEUY-YK3616; **D-F**, *Entactinia* (?) *tanumaensis* Kamata n. sp., **D**, holotype, DEUY-YK3500; **E**, paratype, DEUY-YK3522; **F**, paratype, DEUY-YK3643; **G-M**, *Parentactinia karasawayamaensis* Kamata n. sp., **G**, paratype, DEUY-YK3654; **H**, holotype, DEUY-YK3495; **I**, paratype, DEUY-YK3653; **J**, over view, paratype, DEUY-YK3650; **K**, paratype, DEUY-YK3653; **L**, long apical and basal spines are preserved, paratype, DEUY-YK3657; **M**, over view, paratype, DEUY-YK3533. Scale bars: 100 µm.

ETYMOLOGY. — Species name, sashidai is named for Associate Professor Katsuo Sashida of Tsukuba University in honor of his contribution to the study of Lower Triassic radiolarians.

OCCURRENCE. — Common in TNK-R-08, Kuzu area, central Japan.

DIMENSIONS (µm). — Based on five specimens : shell diameter, 100 to 150 (average 128); length of main spines, 120 to 210 (average 145).

DESCRIPTION

Test small, spherical, spongy with four to six needle-like main spines. Shell wall of some specimens develops minute circular pores and humps. Main spines taper to a point. Spines one to two times diameter of shell. Internal structure unknown.

REMARKS

Entactinosphaera (?) *sashidai* n. sp. is similar to *E. chiakensis* but differs by possessing a spongy shell.

Entactinosphaera chiakensis
Sashida & Igo, 1992
(Fig. 10I, J, L-N)

Entactinosphaera chiakensis Sashida & Igo, 1992: 1302, fig. 14-1-7, 9, 10, 15.

OCCURRENCE. — Common in TNK-R-08, Kuzu area, central Japan. Phatthalung, southern Peninsular Thailand.

REMARKS

This species consists of outer and inner shells with four to six needle-like spines. Two shells are connected by secondary spines.

Family ACTINOMMIDAE Haeckel, 1862
emend. Riedel, 1967
Genus *Thaisphaera* Sashida & Igo, 1992
Thaisphaera (?) ***igoi*** n. sp.
(Fig. 10E-H, K)

TYPES. — Holotype, Figure 10F, TNK-R-08, DEUY-YK3647; paratypes, Figure 10E, TNK-R-08, DEUY-YK3637; Figure 10G, TNK-R-08, DEUY-YK3655; Figure 10H, TNK-R-08, DEUY-YK3622; Figure 10K, TNK-R-08, DEUY-YK3591.

ETYMOLOGY. — The species is named in honor of Prof. Emeritus Hisayoshi Igo who introduced me to the study of the Ashio Terrane.

OCCURRENCE. — Common in TNK-R-08, Kuzu area, central Japan.

DIMENSIONS (µm). — Based on nine specimens: cortical shell diameter, 140 to 180 (average 160); medullary shell diameter, 50 to 60, length of main spines 100 to 180 (average 110); wall thickness 13-20 (average 15); pore diameter less than 20.

DESCRIPTION

Test consisting of a cortical shell with five to six primary spines and an inner medullary shell; both shells are spherical. Cortical shell thin-walled, composed of circular to subcircular pores with small nodes at vertices. Inner shell much smaller than outer shell; diameter approximately one third of the outer shell. Cortical and medullary shells connected by six thin, rod-like beams. Four to five primary spines are thick, three bladed, and taper distally; primary spines aligned with internal beams. Length of primary spines commonly equal to diameter of cortical shell.

REMARKS

Thaisphaera (?) *igoi* n. sp. resembles *Entactinosphaera chiakensis* Sashida & Igo, but differs from it by possessing three-bladed and shorter main spines. *Thaisphaera* (?) *igoi* is also very similar to *T. minuta* Sashida & Igo, but differs by having longer and thicker primary spines.

Family PANTANELLIIDAE Pessagno, 1977
Pantanellium (?) ***virgeum*** Sashida, 1991
(Fig. 11D, G-J, L)

Pantanellium (?) *virgeum* Sashida, 1991: 691, fig. 7-9-14. – Nagai & Mizutani 1993: pl. 3, fig. 4-6. – Kamata 1995: fig. 6-6, 7.

OCCURRENCE. — Rare in TNK-R-08, 09, Kuzu area, Tochigi Prefecture. Mt. Kinkazan and Minokamo City, Gifu Prefecture. Kanto Mountains, Saitama Prefecture, central Japan.

REMARKS

Test composed of an ellipsoidal to subspherical cortical shell, a spherical medullary shell and two rod-like bipolar spines. Well-preserved material

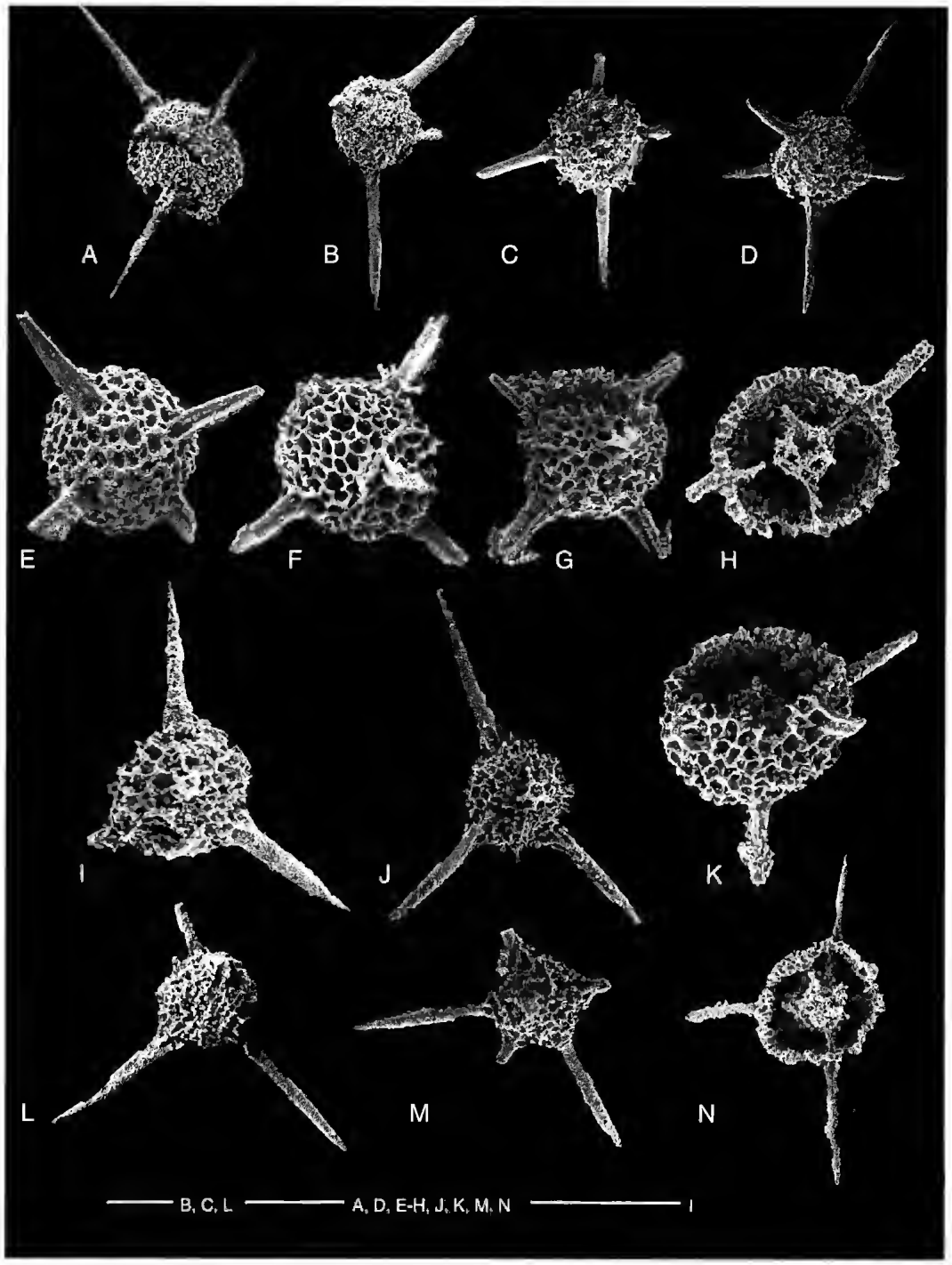

FIG. 10. — **A-D**, *Entactinosphaera* (?) *sashidai* Kamata n. sp., **A**, holotype, DEUY-YK3483, **B**, paratype, DEUY-YK3490; **C**, paratype, DEUY-YK3508; **D**, paratype, DEUY-YK3434; **E-H**, **K**, *Thaisphaera* (?) *igoi* Kamata n. sp.; **E**, paratype, DEUY-YK3637; **F**, holotype, DEUY-YK3647; **G**, paratype, DEUY-YK3655; **H**, showing internal structure, paratype, DEUY-YK3622; **K**, paratype, DEUY-YK3591; **I**, **J**, **L-N**, *Entactinosphaera chiakensis* Sashida & Igo; **I**, DEUY-YK3492; **J**, DEUY-YK3520; **L**, DEUY-YK3421; **M**, DEUY-YK3433; **N**, showing inner shell, DEUY-YK3485. Scale bars: 100 µm.

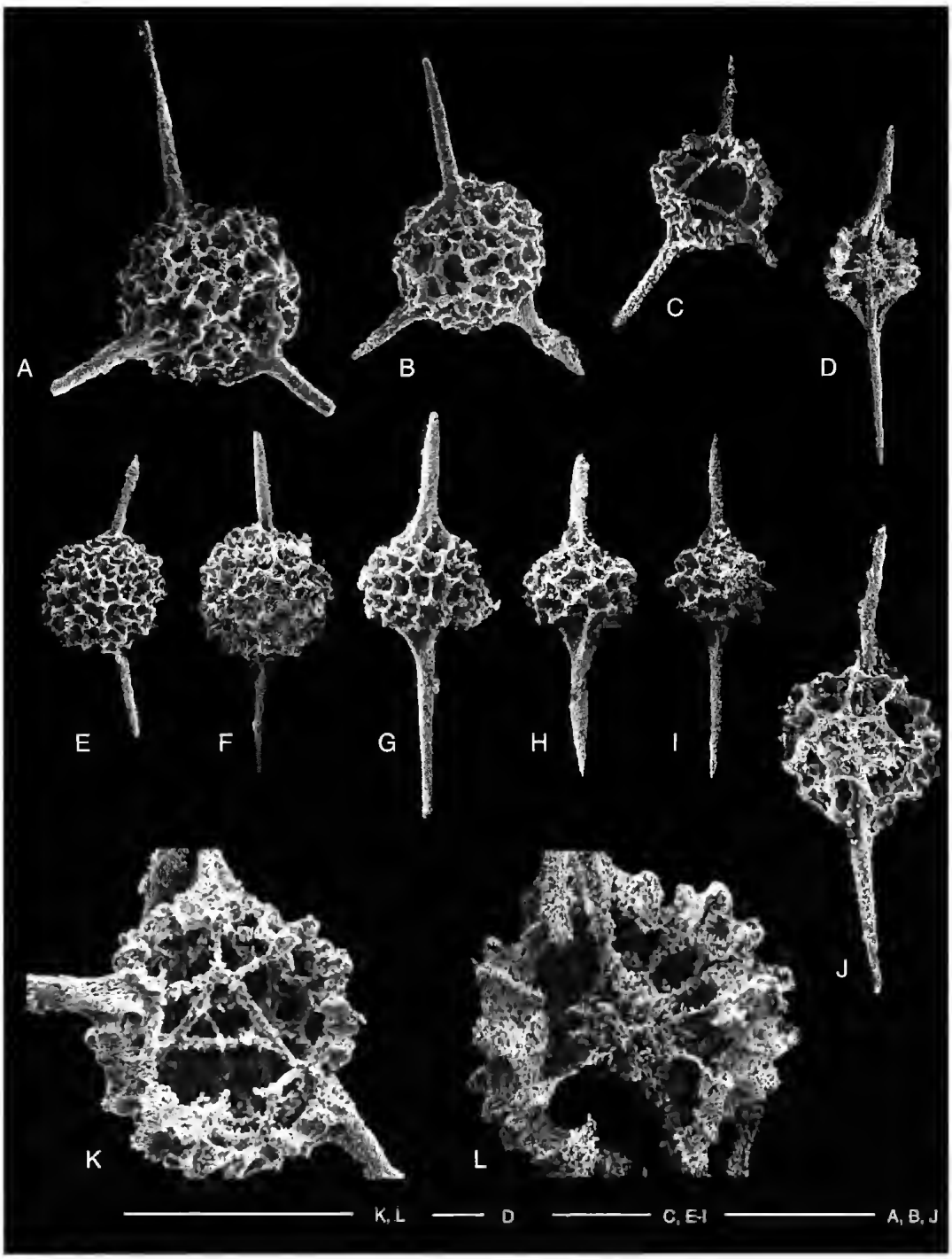

FIG. 11. — **A-C**, **K**, *Cryptostephanidium longispinosum* (Sashida); **A**, DEUY-YK3625; **B**, DEUY-YK3634; **C**, showing arch-like skeleton of aj, DEUY-YK3641; **K**, showing internal structure of A, L, D, and V spinules, DEUY-YK3633; **D**, **G-J**, **L**, *Pantanellium* (?) *virgeum* Sashida; **D**, DEUY-YK3474; **G**, DEUY-YK3614; **H**, DEUY-YK3649; **I**, DEUY-YK3438; **J**, DEUY-YK3498; **L**, enlargement of D showing cortical shell and beams, DEUY-YK3475; **E**, **F**, *Pantanellium* (?) sp. A; **E**, DEUY-YK3466; **F**, DEUY-YK3430. Scale bars: 100 µm.

shows the medullary shell connected to the cortical shell by numerous radial beams (Fig. 11D, L).

Pantanellium (?) sp. A
(Fig. 11E, F)

FIGURED SPECIMENS. — Figure 11E, TNK-R-08, DEUY-YK3466; Figure 11F, TNK-R-08, DEUY-YK3430.

OCCURRENCE. — Rare in TNK-R-08, 09, Kuzu area, central Japan.

REMARKS
Test consists of a subspherical to spherical shell with bipolar spines. Shell wall has very small, irregular elliptical to circular pores with well-developed nodes. Bipolar spines very thin and possessing slight grooves proximally.
Pantanellium (?) sp. A is distinguished from *P.* (?) *virgeum* Sashida by having thin spines and a spherical to subspherical shell with many pores.

Suborder NASSELLARIA Ehrenberg, 1875
Family EPTINGIIDAE Dumitrica, 1978a
Genus *Cryptostephanidium* Dumitrica, 1978a

Cryptostephanidium longispinosum
(Sashida, 1991)
(Fig. 11A-C, K)

Spongostephanidium longispinosum Sashida, 1991: 694, fig. 7-1-8.
? *Tripocyclia japonica* Nakaseko & Nishimura, 1979 – Blome *et al.* 1986, pl. 8.3, fig. 18.
Cryptostephanidium longispinosum (Sashida) – Sugiyama 1992: 1205, fig. 13-1, 2. – Nagai & Mizutani 1993: pl. 2, fig. 1-3. – Kamata 1995: 28, figs 6-16.

OCCURRENCE. — Abundant in TNK-R-08, 09, Kuzu area, Tochigi Prefecture. Mt. Kinkazan and Minokamo City, Gifu Prefecture. Kanto Mountains, Saitama Prefecture, central Japan. Oregon USA.

REMARKS
Studied specimens are quite similar to those above listed for *Cryptostephanidium longispinosum*. Internal shell structure is well observed in broken specimens (e.g., Fig. 11-C, K) which clearly show a MB, long apical and primary lateral spines, and the vertical and dorsal spines as well as the sagittal ring.

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I would like to thank Professor Emeritus H. Igo (Institute of the Geoscience, University of Tsukuba) for his valuable suggestions throughout the course of this study. I heartily thank Prof. T. Koike (Institute of Geology, Yokohama National University of Yokohama) for conodont identifications and important suggestions; Associate Prof. K. Sashida (Institute of Geoscience, University of Tsukuba) for his suggestions and critical reading of the manuscript; and P. Dumitrica, S. Gorican, and A. Ohler for their rigorous review and variable comments and suggestions. Finally, special thanks to E. S. Carter for her revision of English text of the manuscript.

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Radiolarian biostratigraphy of the Jurassic-Early Cretaceous chert-clastic sequence in the Taukha Terrane (South Sikhote-Alin, Russia)

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ABSTRACT

This paper presents the results of biostratigraphic investigations of cherty and terrigenous deposits from the Taukha Terrane. Twelve successive radiolarian assemblages which correspond to the upper Pliensbachian-lower Toarcian, lower-middle Toarcian, upper Toarcian-middle Aalenian, upper Aalenian-lower Bajocian, middle Bajocian, upper Bajocian-lower Bathonian, middle Bathonian-lower Callovian, middle Oxfordian-lower Kimmeridgian, middle-upper Kimmeridgian, lower-middle Tithonian, upper Tithonian, and lower Valanginian-lower Barremian deposits of the continuous section have been distinguished. Characteristics of the radiolarian assemblages are shortly given.

KEY WORDS
Radiolaria,
Jurassic,
Early Cretaceous,
Taukha Terrane,
Sikhote-Alin,
accretionary prism.

RÉSUMÉ

Biostratigraphie à radiolaire d'une séquence siliciclastique d'âge jurassique-crétacé inférieur dans la Taukha Terrane (sud de Sikhote-Alin, Russie).

Cet article présente les résultats d'une recherche biostratigraphique réalisée sur des dépôts siliceux et détritiques de la Taukha Terrane. Une douzaine d'assemblages consécutifs de radiolaires a pu être reconnue dans les sédiments d'une série continue où l'on peut reconnaitre le Pliensbachien supérieur-Toarcien inférieur, le Toarcien moyen inférieur, le Toarcien supérieur-Aalenien moyen, l'Aalénien supérieur-Bajocien inférieur, le Bajocien moyen, le Bajocien supérieur-Bathonien inférieur, le Bathonien moyen-Callovien inférieur, l'Oxfordien moyen-Kimmeridgien inférieur, le Kimmeridgien moyen supérieur, le Tithonique inférieur à moyen, le Tithonique supérieur et le Valanginien inférieur-Barrémien inférieur. De brèves descriptions des assemblages à radiolaires sont données.

MOTS CLÉS
Radiolaires,
Jurassique,
Crétacé inférieur,
Taukha Terrane,
Sikhote-Alin,
prisme d'accrétion.

INTRODUCTION

Cherty rocks are important in the geological structure of the South Sikhote-Alin. They comprise up to 35% of the sections of Mesozoic accretionary prisms, that are among the main structural units of the region. However, paleontology of these cherts is, in most cases, poorly studied. Cherts have been described from separate samples that allowed them to be dated accurately to a period or an epoch. The ranges of the microfaunal species in them have not been traced. Also, elementary biostratigraphic subdivision has not been constructed and therefore, comparison and correlation of the various species could not be carried out. The study of Permian chert deposits is relatively more successful, since biostratigraphic subdivisions and zonal scales have been proposed (Rudenko 1991). Some local sections of Triassic (Volokhin *et al.* 1990; Bragin 1991; Smirnova & Lepeshko 1991) and Early Jurassic cherts (Kemkin & Golozoubov 1996) have also been studied, and layers with different microfaunal assemblages have been distinguished. The younger cherty formations have not been broken down into elementary biostratigraphic subdivisions with the exception of preliminary data on Gorboushinskaya suite (Bragin 1993). Given below are the results of the microfaunal study of the most complete chert sections and overlying terrigenous deposits of the Taukha Terrane, exposed on the left bank of Roudnaya River (south-east of Dalnegorsk Town).

GEOLOGICAL SETTING OF THE REGION

The Dalnegorsk Region is situated within the Taukha Terrane (Fig. 1), an Early Cretaceous accretionary prism (Khanchuk *et al.* 1989; Golozoubov *et al.* 1992; Kemkin & Khanchuk 1993). The prism structure is a complicated combination of different-facies and different-age formations. The Taukha Terrane is composed of a repeated alternation of turbidite and olistostrome deposits constituting the matrix, and different-age accreted fragments of mostly paleoceanic, rarely paleocontinental formations. Section of the prism can be visualized as a "multi-layered cake", where relatively young deposits of the matrix alternate with more ancient accreted formations.

The accreted fragments comprise extensive (up to several tens of kilometers long) plates as well as blocks and lumps of varying sizes within the matrix of olistostrome. Both plate and matrix rocks were crumpled together into assymetric north-east trending folds with a south-east vergence. Some plates can be 500 m thick. Such a thickness is a result of the tectonic repetition (3-5 times) of some parts of accreted formations. A true thickness, for example, of cherty rocks does not exceed 100 m. The contacts between plates of the accreted fragments and the matrix (if they are not broken by later deformations) are sedimentary, distinct in lithology. Large plates usually overlie the olistostrome.

Paleoceanic accreted formations are represented by siliceous (fragments of abyssal plains) and carbonaceous (fragments of paleoguyots) facies. These facies are composed of typical bedded-cherts, dated from their different plates by Middle Carboniferous to Late Jurassic age (Rybalka 1987; Khanchuk *et al.* 1988; Bragin *et al.* 1988; Rudenko & Panasenko 1990; Volokhin *et al.* 1990; Bragin 1993), and reef-forming limestones laying on high-titanium alkaline basalts. The age of the limestone basal layers in different plates and blocks ranges from Late Devonian to Late Triassic (Nikitina 1971; Vorobeva *et al.* 1978; Bersenev 1986; Burii *et al.* 1986).

The fragments of paleocontinental formations are represented by blocks and lumps of shallow-marine (shelf) deposits containing Middle-Late Triassic macrofauna, and by plates of relatively deep-sea Permian rocks composed of sandstones and siltstones flysch alternation (Kemkin 1996).

RADIOLARIAN ASSEMBLAGES

Detailed study of cherty formations from the Taukha Terrane along the left bank of the Roudnaya River (Dalnegorsk Town area) have been carried out. The cherts and overlying turbidites of the matrix form four tectonically repeated plates (Fig. 1). The most representative

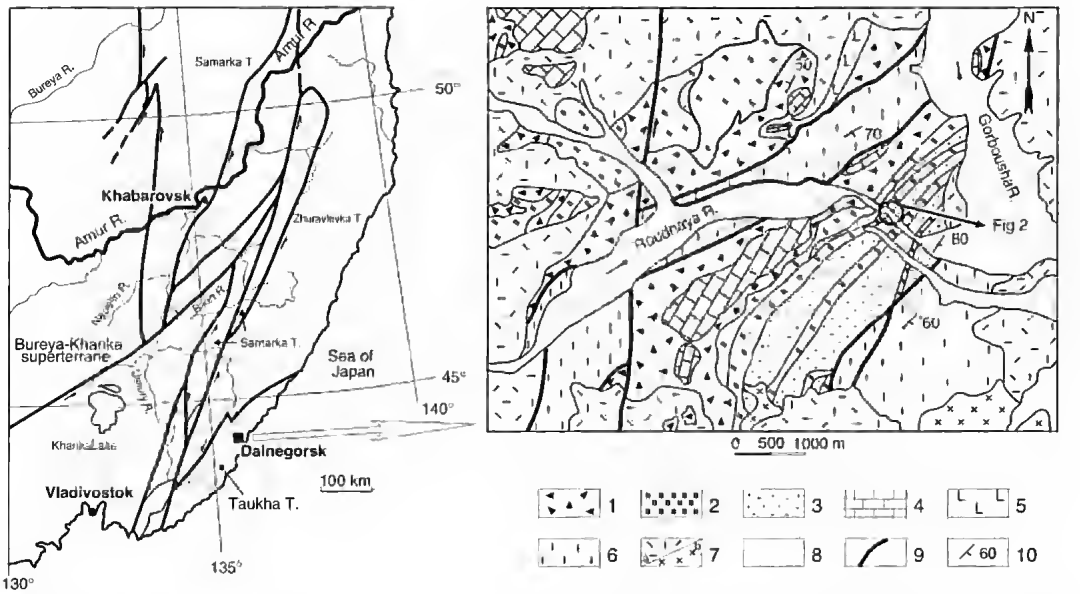


FIG. 1. — Tectonic scheme of the Sikhote-Alin Region and geological map of the investigated area. **1**, Early Cretaceous olistostrome formations of the accretionary prism matrix; **2**, plates and blocks of Triassic-Jurassic cherts; **3**, turbidite deposits of the matrix; **4**, plates and blocks of Middle-Late Triassic limestones; **5**, high-titanium alkaline basalts underlying limestones; **6**, Early Cretaceous shallow-marine (shelf) deposits; **7a**, Late Cretaceous volcanites; **7b**, intrusive formations; **8**, Quaternary deposits; **9**, dislocations with a break in continuity; **10**, elements of rock occurrence (strikes and dips).

section of the cherts was discovered in the second tectonic plate (Fig. 2) where they make up its lower portion. Within the exposure, the rocks show monoclinal dip to the southeast (dip azimuth, 130-140°, angle 70-80°). The cherts have bedded texture that is caused by thin (1-3 mm) clayey interbeds. Thickness of the chert beds varies from 1.5-2 to 3-5 cm, more rarely 7-10 cm. The rocks are broken by a series of steeply-dipping, discontinuous dislocations of northeast and submeridional trending, parallel or at angle to bedding. In the upper part of the section, the cherty formations changes to terrigenous deposits, cherty mudstones, mudstones, muddy siltstones and, then, flysch alternation of siltstones and sandstones that grade into massive sandstones. Unfortunately, the contact of cherts and terrigenous rocks at this exposure is complicated by a fault, as evidenced by the presence of boudinaged fragments of cherts in the contact part of the cherty mudstones. However, in other places (for example, Koreyskaya River area) we observe a conformable and gradual transition. The conformable and gradual transition between cherts and terrigenous deposits is very important because it indicates a smooth change of environment of sedimentation from pelagic to marginal-continental (chert accumulation is changed at the begining by the accumulation of fine and then coarse terrigenous material). This evidence fixes, thus, the moment of approach of a given part of the oceanic plate to the zone of accretion. All three Triassic and Lower Jurassic epochs have been identified in the chert units (Volokhin *et al.* 1990; Bragin 1991; Bragin 1993). According to Bragin (1993), Middle Jurassic is not represented in the section due to the essential stratigraphical break in the Middle Jurassic time. The available data on the Late Jurassic age of the cherts (Bragin 1993) are not quite correct, as the Late Jurassic Radiolaria have been separated from the cherty mudstones belonging to a transitional chert-to-terrigenous packet. The age of the terrigenous portion of the section has been determined as middle Tithonian-Valanginian (Bragin 1993). The Triassic part of the section is detaily subdivided into detailed zones by conodonts and radiolarians (Volokhin *et al.* 1990; Bragin 1991) and

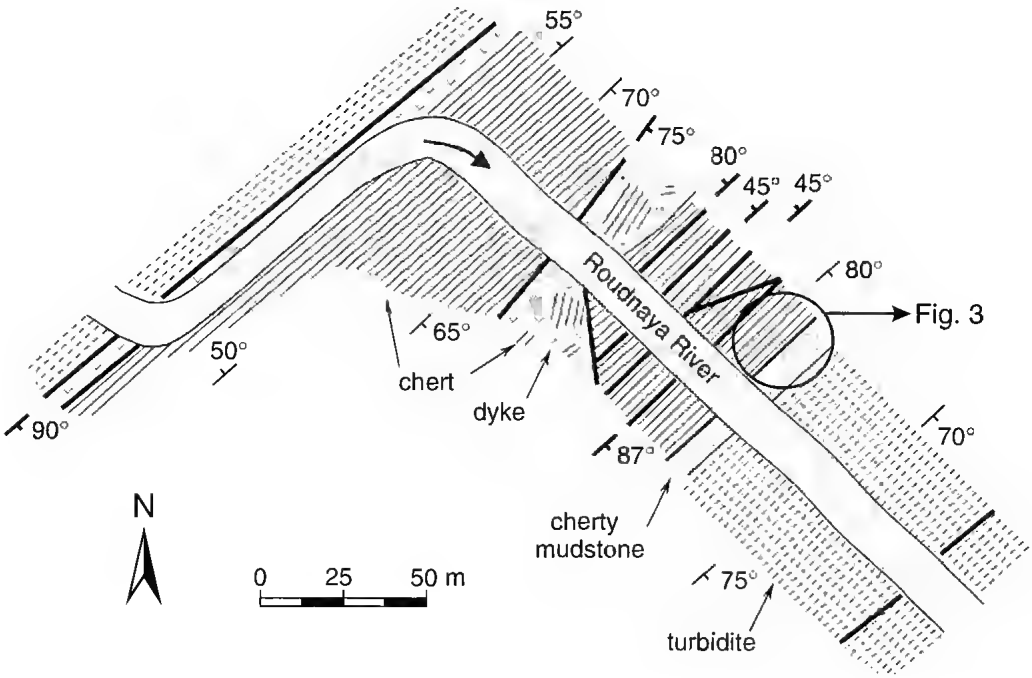


FIG. 2. — Geological scheme illustrating the structure of chert-terrigenous successions of the second tectonic plate along the Roudnaya River (Dalnegorsk Town).

is not discussed in this paper. In this study the Jurassic parts of the cherts and terrigenous rocks have been sampled in great detail. The microfaunal study shows that the cherty beds of the section contain Early, Middle and Late Jurassic radiolarians. The Late Jurassic and Early Cretaceous ones were found in terrigenous deposits (Figs 3, 5). Altogether, twelve successive radiolarian assemblages have been distinguished (Figs 3, 4). Short descriptions of these assemblages are given below in ascending order.

1. *Parahsuum longiconicum* assemblage was found in cherts of deep-grey to black in colour (samples P-21, P-20, P-19). Specific composition of the assemblage is not abundant (Fig. 3). This assemblage contains nassellarians such as *Parahsuum*, *Canoptum*, *Tricolocapsa* and *Parvicingula* and spumellarians – *Triactoma*. Age diagnostic species is *Parahsuum longiconicum*. The geological range of the assemblage is assigned to Pliensbachian-early Toarcian. The lower age boundary is assumed to be late Pliensbachian according to the first appearance of the species-index (Sashida 1988). The upper boundary is restricted by the lower one of the upward following assemblage. The assemblage is comparable in age and specific composition (Fig. 4) with the assemblage of *Parahsuum takarazawaense* zone (Sashida 1988) and subzone 4 of *Parahsuum simplum* zone (Hori 1990; Matsuoka *et al.* 1994), and lower part of *Trillus elkhornensis* zone (Matsuoka 1995) reported from Japan.

2. *Hsuum altile* assemblage was extracted from violet-deep-grey cherts (samples P-18, P-17). The assemblage characterized by a relative diversity of species (Fig. 3), with a predominance of *Parahsuum* and *Hsuum*. Some spumellarians such as *Triactoma* and others are also found here. The geological age of the assemblage is early Toarcian-middle Toarcian. Its lower boundary was defined by the appearances of *Hsuum altile*, *Hsuum transiensis*, *Parvicingula nanoconica* that have been noted since early Toarcian (Hori & Otsuka 1989; Hori 1990). The upper boundary is controlled by the upper assemblage and the last appearance of *Parahsuum longiconicum* spe-

cies (Sashida 1988). Age and the specific composition of this assemblage are comparable with that of *Mesosaturnalis hexagonus* zone (Hori 1990; Matsuoka *et al.* 1994), and partially correlative with the assemblage of *Hsuum minoratum* zone (Sashida 1988) and upper parts of *Trillus elkornensis* zone (Matsuoka 1995) also reported from Japan.

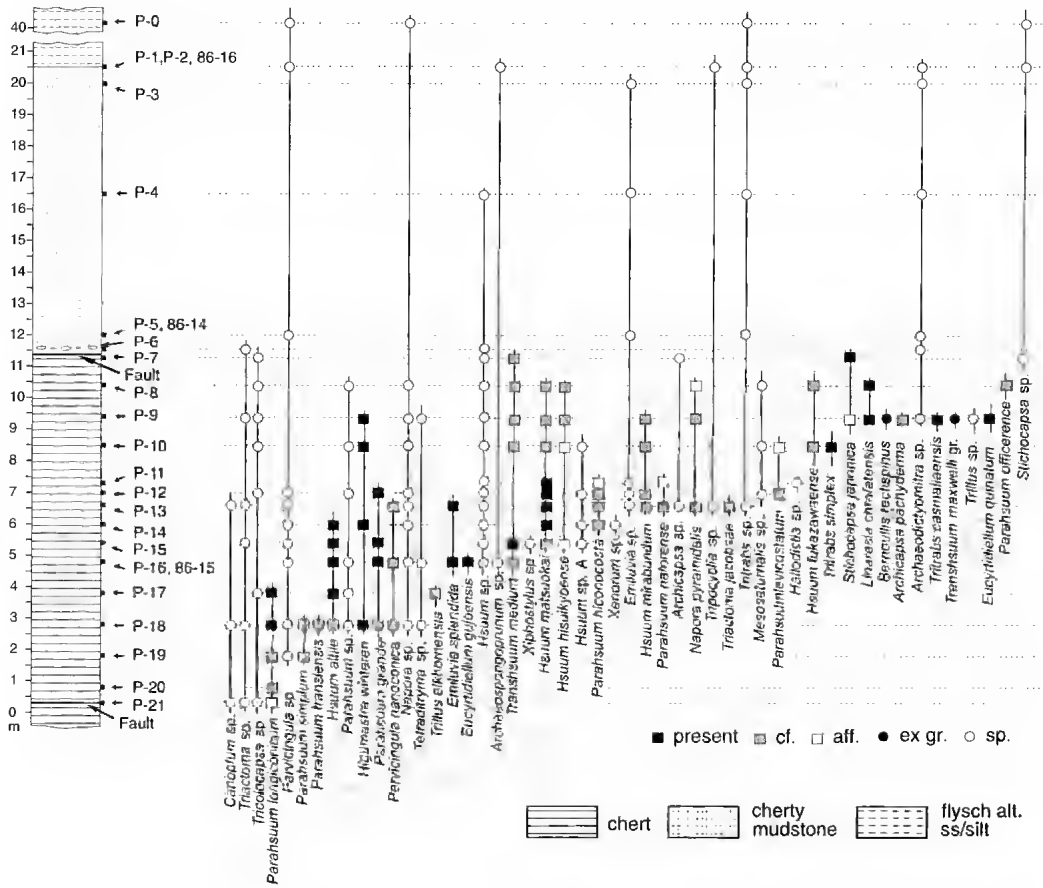
3. *Parahsuum grande* assemblage was found in the identical violet-deep-grey cherts (samples P-16, P-15, 86-15). This assemblage contains abundant and diverse representatives of nassellarians such as *Parahsuum*, *Hsuum*, and *Parvicingula*, and spumellarians such as *Emiluvia*, *Tetraditrima*, *Archaeospongoprunum*, *Xiphostilus* and others (Fig. 3). Age diagnostic species are *Parahsuum grande*, *Hsuum matsuokai* and *Hsuum hisuikyoense*. The age of the assemblage is late Toarcian-middle Aalenian. According to the first appearance of *Parahsuum grande* (Hori 1990), the older age boundary was assumed. The top is limited by the lower boundary of the upper assemblage. The assemblage is comparable with that of *Parahsuum grande* zone, and the lower portion of *Hsuum hisuikyoense* zone (Hori 1990; Matsuoka *et al.* 1994), as well as *Laxtorum jurassicum* zone (Marsuoka 1995). All zones have been identified in Japan.

4. *Parahsuum hiconocosta* assemblage was found in deep-gtey cherts (sample P-14). *Parahsuum and Hsuum* predominate among the representatives that are not relarively numetous in this assemblage (Fig. 3). The geological age of the assemblage is late Aalenian-early Bajocian. The lower age boundary corresponds to the first appearance of the species-index (Baumgartnet *et al.* 1995). The top is controlled by the lower botundaty of the upper assemblage. The assemblage is correlated with that of the *Hsuum hisuikyoense* zone, lower part of the *Unuma echinatus* zone (Matsuoka *et al.* 1994), and upper parts of the *Laxtorum jurassicum* zone (Matsuoka 1995).

5. *Hsuum mirabundum* assemblage was extracted from blue-grey cherts (samples P-13, P-12, P-11). This assemblage shows relative specific diversity. Among the representatives, nassellarians such as *Hsuum*, *Parahsuum*, *Parvicingula* and *Tricolocapsa*, as well as spumellarians ie *Emiluvia*, *Tripocyclia* and others are prevailing (Fig. 3). The geological range of the assemblage is assumed to be early-late middle Bajocian. The lower boundary was determined by the first appearance of *Hsuum mirabundum* (Baumgartnet *et al.* 1995). The upper boundary is restricted by the last appearance of such species as *Parahsuum natorense*, *Parahsuum grande*, *Emiluvia splendida*. The boundary corresponds to the end of middle Bajocian (Hori 1990; Baumgartner *et al.* 1995). This assemblage is comparable in age with that of the middle part of the *Unuma echinatus* zone (Matsuoka *et al.* 1994), and lower part of the *Tricolocapsa plicarum* zone (Matsuoka 1995) distinguished in Japan.

6. *Hsuum matsuokai* assemblage was found in light-grey cherts (samples P-10, P-9, P-8). Specific compositions of the assemblage is characterized by the essential diversity of species. Among them, there are nassellarians: *Hsuum*, *Transhsuum*, *Parahsuum*, *Arhaeodicryomitra*, *Tricolocapsa*, and spumellatians such as *Mesosaturnalis*, *Tritrabs*, *Tetraditrima* and others (Fig. 3). Age diagnostic species are *Tritrabs casmaliaensis* and *Hsuum matsuokai*. The range of the assemblage was determined as late Bajocian-early Bathonian. The lower age botundary is based on the absence of chatacteristic species of the end of middle Bajocian (see assemblage 5), as well as the presence of *Tritrabs casmaliaensis* characteristic of late Bajocian (Baumgartner *et al.* 1995). The upper boundary was determined by the last appearance of *Hsuum matsuokai* rhat had completed its evolution in the early Bathonian (Baumgartner *et al.* 1995). This assemblage is correlated with thar of the upper parts of *Unuma echinatus* (Matsuoka *et al.* 1994) and *Tricolocapsa plicarum* (Matsuoka 1995) zones.

7. *Triactoma tithonianum* assemblage was found in greenish-grey cherts (samples P-7), 10 cm below the bottom of the cherty mudstones. *Tricolocapsa* and *Stichocapsa* predominate among the representatives that are not relatively numerous in this assemblage (Fig. 3). The geological age of the assemblage is identified as middle Bathonian-early Callovian. The lower age boundary corresponds to the upper boundary of the previous assemblage and ro the firsr appearance of *Triactoma tithonianum* (Baumgartner *et al.*



1995). The upper age boundary is restricted by the last appearance of *Transhsuum medium* (Baumgartner *et al.* 1995). The assemblage is comparable in age to that of the *Guexella nudata* (Matsuoka *et al.* 1994), and the *Tricolocapsa conexa* (Matsuoka 1995) zones.

8. *Archaeodictyomitra minoensis* assemblage was extracted from the boudinaged fragments of cherts (sample P-6) in the contact zone of cherts and cherty mudstones. This radiolarian assemblage contains mainly nassellarians and is characterized by rich specific diversity. They are *Archaeodictyomitra*, *Xitus*, *Mirifusus*, *Hsuum*, *Sethocapsa*, *Pseudodictyomitra*, *Stichocapsa* and others. The range of the assemblage is middle Oxfordian-early Kimmeridgian. Assumed lower age boundary is from the first appearance of the species-index (Baumgartner *et al.* 1995). The upper boundary corresponds to the last appearance of *Haliodicta hojnosi* (Baumgartner *et al.* 1995). The assemblage is comparable in age with that of the upper parts of the *Stylocapsa spiralis* zone (Matsuoka 1995) described in Japan. It should be noted (that within the assemblage) there are several morphological forms that are more common in Early Cretaceous radiolarians (Figs 3, 5).

9. *Pseudodictyomitra okamurai* assemblage was found in green cherty mudstones (samples P-5, 86-14). The assemblage also contains numerous and diverse radiolarian species (Fig. 3). Predominant ones are *Archaeodictyomitra* and *Pseudodictyomitra*. The range of the assemblage is middle-late Kimmeridgian. The older age boundary is somewhat tentative, but the data on the previous assemblage have been taken into account. The upper age limit is restricted by the last appearance of *Pseudodictyomitra okamurai* (Baumgartner *et al.* 1995). The assemblage is

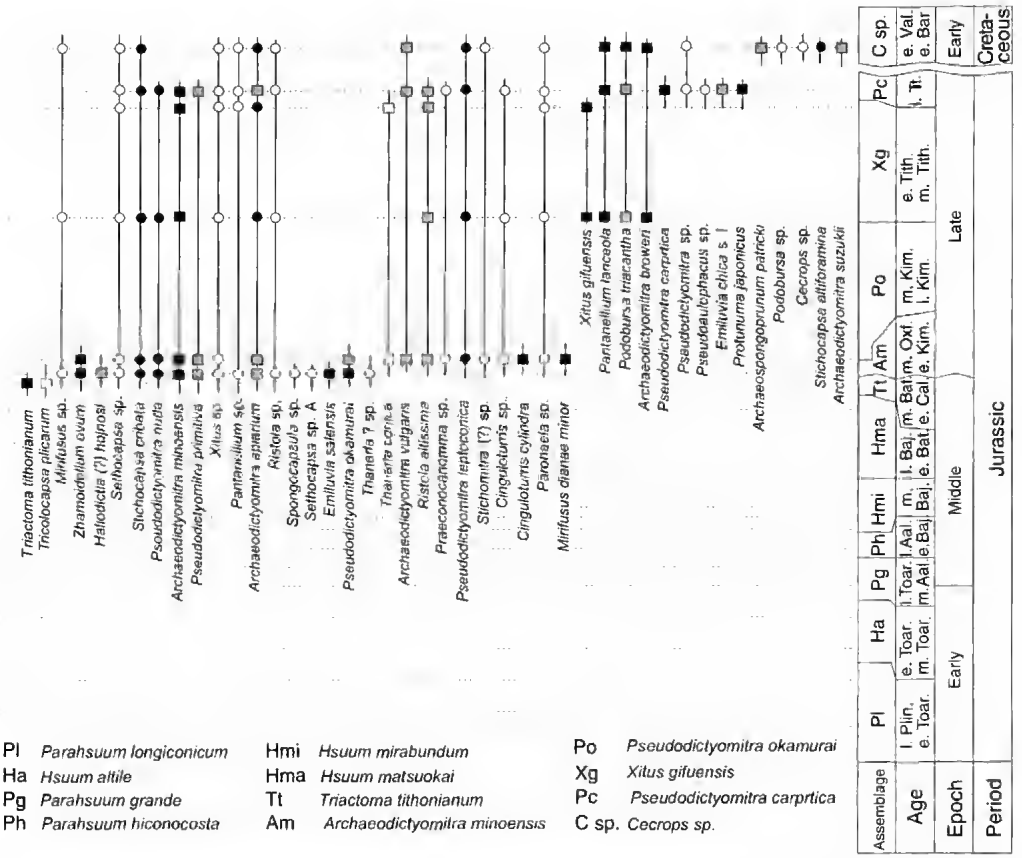


FIG. 3. — Litho- and biostratigraphical column of the Jurassic portion of the chert section and overlying cherts terrigenous deposits, enclosing radiolarian species and assemblage range along the section.

comparable in age with that of *Hsuum maxwelli* zone (Matsuoka 1995). Morphological features of some species are more common in the Early Cretaceous forms. They are ? *Pseudodictyomitra nuda* and ? *Pseudodictyomitra leptoconica* (Figs 3, 5) and also characteristic in this assemblage.

10. *Xitus gifuensis* assemblage was also found in green cherty mudstones (samples P-4, P-3). *Archaeodityomitra* and *Xitus* predominate among the numerous radiolarians of this assemblage. Some spumellarians such as *Tritrabs*, *Emiluvia* and *Pantanellium* are also found. The geological range of the assemblage is assumed as early-middle Tithonian. The lower age boundary corresponds to the first appearance of *Xitus gifuensis* (Baumgartner *et al.* 1995). The upper boundary is restricted by the lower boundary of the upper assemblage. The assemblage is correlated with that of the *Pseudodictyomitra primitiva* zone (Matsuoka 1995) and also contains some species similar to *Pseudodictyomitra nuda* and *Pseudodictyomitra leptoconica*.

11. *Pseudodictyomitra carpatica* assemblage was found in black mudstones (samples P-1, P-2, 86-16) very close to the contact with green cherty mudstones. The assemblage is represented by numerous and diverse radiolarians related to the end of Jurassic and beginning of Cretaceous time (Fig. 3). Nassellarians such as *Pseudodictyomitra*, *Archaeodictyomitra*, *Xitus*, *Thanarla*, *Sethocapsa* predominate. Spumellarians such as *Tritrabs*, *Emiluvia*, *Pantanellium* and others are also contained. The range of the assemblage is late Tithonian. The lower age boundary corresponds to the first appearance of *Pseudodictyomitra carpatica* (Matsuoka 1992). The upper boundary is

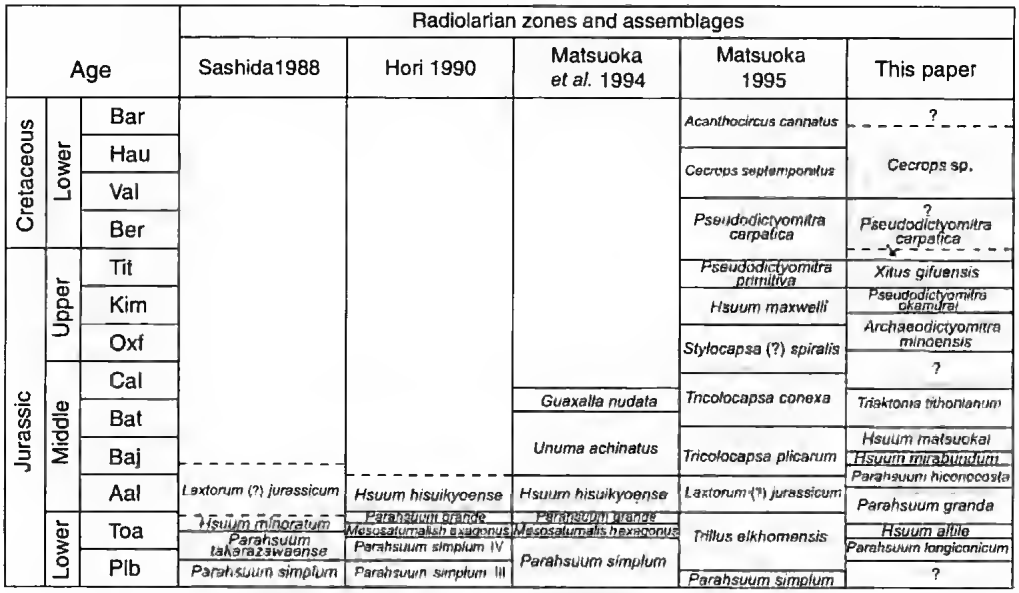


Fig. 4. — Correlation table of Taukha Terrane and Japanese radiolarian zones and assemblages.

determined by the last appearance of *Archaeodictyomitra minoensis*, *Ristola altissima* and *Protunuma japonicus* (Baumgartner *et al.* 1995). This assemblage contains the species similar to *Pseudodictyomitra nuda* and *Pseudodictyomitra leptoconica*. The assemblage is comparable in age with that of the lower part of *Pseudodictyomitra carpatica* zone (Matsuoka 1995) established in Japan.

12. *Cecrops* sp. assemblage was distinguished in the black mudstones (sample P-0) that is 40 m above the horizon P-1 of the section. The assemblage is characterized by diverse and abundant radiolarian species (Fig. 3). Most of them have a wide age interval. However, the presence of *Cecrops* sp. and *Stichocapsa* ex. gr. *altiforamina* allows to determine range interval of the early Valanginian-early Barremian (Baumgartner *et al.* 1995). This assemblage is comparable in age with that of *Cecrops septemporatus* zone and lower parts of *Acanthocircus carinatus* zone (Matsuoka 1995).

CONCLUSION

We have carried out detailed biostratigraphical investigations. Twelve successive radiolarian assemblages which characterize different-age deposits of the chert-turbidite section were distinguished. Eight assemblages are included in the chert portion ranging from late Pliensbachian to early Kimmeridgian. It indicates that the chert accumulation process in Jurassic time was continuous. The presence of Middle Jurassic radiolarians (of all stages) dispute the presence of any significant stratigraphical break in Jurassic time, as was previously reported (Bragin 1993). At the same time, some chert portion, corresponding to middle Callovian-early Oxfordian time interval, as well as some of cherty mudstones is absent from the section as a result of later deformations. In the transitional packet of cherty mudstones and in the terrigenous rocks, we have established two radiolarian assemblages in each, indicating Kimmeridgian-Tithonian and late Tithonian-Early Cretaceous age of these deposits correspondingly. These data suggest that one paleogeodynamic environment of sedimentation was replaced by another at the end of Jurassic time, and that chert accretion took place in Early Cretaceous time.

Cherty formations analogous in age are known today among different accretionary prisms of the Pacific margin of Asia, from Koryak plateau

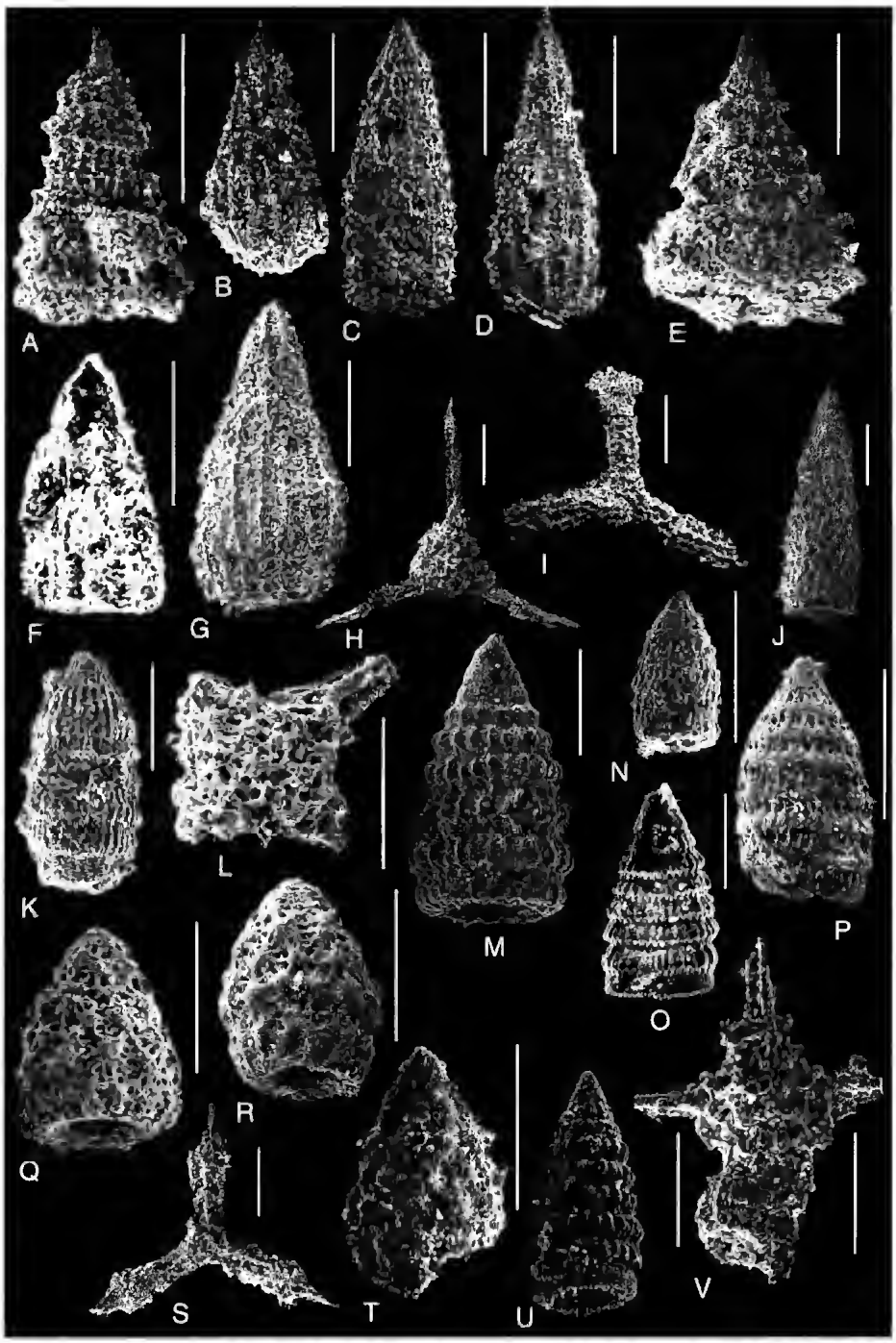


FIG. 5. — Some Jurassic and Early Cretaceous radiolarians from chert-terrigenous sequence of the Taukha Terrane. **A**, *Parahsuum* cf. *longiconicum* Sashida, P-17; **B**, *Hsuum altile* Hori & Otsuka, P-18, **C**, *Parahsuum grande* Hori & Yao, P-15; **D**, *Hsuum* sp. A, P-14; **E**, *Parahsuum* cf. *hiconocosta* Baumgartner & De Wever, P-14; **F**, *Hsuum* cf. *mirabundum* Pessagno & Whalen, P-13; **G**, *Hsuum matsuokai* Isozaki & Matsuda, P-8; **H**, *Triactoma tithonianum* Rust, P-7; **I**, *Tritrabs* cf. *casmaliaensis* (Pesagno), P-9, **J**, *Transhsuum medium* Takemura, P-8; **K**, *Archaeodictyomitra minoensis* (Mizutani), P-6; **L**, *Haliodictya* (?) cf. *hajnosi* Riedel & Sanfilippo, P-6; **M**, *Pseudodictyomitra okamurai* Mizutani, P-6; **N**, **P**, ? *Pseudodictyomitra* aff. *Nuda* Shaaf; **N**, P-6; **P**, P-4; **O**, ? *Pseudodictyomitra* aff. *Leptoconica* (Foreman), 86-14; **Q**, **R**, *Xitus gifuensis* Misutani, P-3; **S**, *Tritrabs simplex* Kito & De Wever, P-10; **T**, *Stichocapsa* ex gr. *altiforamina* Tumanda, P-0; **U**, *Pseudodictyomitra carpatica* (Lozynyak), P-2; **V**, *Cecrops* sp., P-0. Scale bars: 100 µm.

(Vishnevskaya & Filatova 1996; Kemkin *et al.* 1996 and others) to the Japanese Islands (Hori & Otsuka 1989; Hori 1990; Ichikawa *et al.* 1990; Matsuoka & Yao 1990; Mizutani *et al.* 1990; Matsuoka *et al.* 1994 and others). This fact together with data on the prism age is evidence of the existence of a single accretionary system along the western boundary of the Paleopacific in Late Jurassic-Early Cretaceous time and allows us to outline general tendencies of geological evolution of the Far East region at a given time interval.

It is interesting to note that our study has recognized among radiolarian assemblages (since Oxfordian-Kimmeridgian time) the presence of separate specimens with morphological features characteristic in Tethys area for Early Cretaceous (Valanginian and younger) forms. They are ? *Pseudodictyomitra* aff. *nuda* and ? *Pseudodictyomitra* aff. *leptonica* range intervals which, according to the currently available data (Baumgartner *et al.* 1995) are early Valanginian-Aptian and late Barremian-Aptian, correspondingly. It's likely that for different reasons, these morphological features in radiolarians of the Paleopacific area began to develop much earlier than in those of the Tethys area.

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Combined radiolarian-ammonite stratigraphy for the Late Jurassic of the Antarctic Peninsula: implications for radiolarian stratigraphy

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ABSTRACT
New biostratigraphic data from co-occurring radiolarians and ammonites in Upper Jurassic sequences of the Antarctic Peninsula (Byers Peninsula on Livingston Island and Longing Gap, Graham Land), permit a revised and more refined regional stratigraphy. The new data also allow a revision of the chronostratigraphic assignment of some American radiolarian zones established by Pessagno and collaborators: the boundary of Zone 3-4 is assigned to the latest Kimmeridgian, contrasting the former assignment to the early/late Tithonian boundary. The boundary between Subzone 4 beta and 4 alpha is assigned to the early Tithonian, but was usually correlated with the early late Tithonian/late late Tithonian boundary. The new chronostratigraphic data from Antarctica are used together with recent results of Baumgartner and collaborators to revise the age assignment of the North American Late Jurassic radiolarian zones.

KEY WORDS
Radiolaria, ammonites, Late Jurassic, Kimmeridgian, Tithonian, biostratigraphy, Antarctic Peninsula.

RÉSUMÉ

Stratigraphie combinée de radiolaires et ammonites du Jurassique supérieur de la péninsule Antarctique : implications pour la stratigraphie des radiolaires.

De nouvelles données biostratigraphiques obtenues à partir de co-occurences de radiolaires et ammonites dans les séries du Jurassique supérieur de la péninsule Antarctique (péninsule Byers sur l'île de Livingston et de Longing Gap, Graham Land), permettent de réviser et affiner une stratigraphie régionale. Les nouvelles données permettent aussi une révision des attributions chronostratigraphiques de quelques zonations de radiolaires américaines établies par Pessagno et ses collaborateurs : la limite de la zone 3-4 est assignée au Kimméridgien le plus tardif, contrastant ainsi avec la précédente assignation à la limite Tithonien précoce-tardif. La limite entre la sous-zone 4 beta et 4 alpha est assignée au Tithonien inférieur mais fut habituellement corrélée avec la limite entre les parties inférieure et supérieure du Tithonien supérieur. Les nouvelles données chronostratigraphiques de l'Antarctique sont utilisées en même temps que les résultats récents de Baumgartner et ses collaborateurs pour réviser les attributions d'âge des zones à radiolaires du Jurassique supérieur d'Amérique du Nord.

MOTS CLÉS
Radiolaires,
Ammonites,
Jurassique supérieur,
Kimméridgien,
Tithonien,
biostratigraphie,
péninsule Antarctique.

INTRODUCTION

Although Upper Jurassic sequences with co-occurring radiolarians and ammonites were continuously reported in the last few years (e.g. Pessagno *et al.* 1987a, b; O'Dogherty *et al.* 1989, 1995; Pujana 1989, 1991, 1996; Baumgartner *et al.* 1995b; Zügel 1997), such findings can still be regarded exceptional. Hence, new sections yielding both radiolarian and ammonite faunas are of high value for the improvement of biostratigraphy.

Late Jurassic mudstone sequences of the Antarctic Peninsula contain relatively well-preserved ammonites and radiolarians at several localities. Two sections are described in this paper. The sections belong to the Anchorage Formation (Byers Peninsula, Livingston Island) and Ameghino (= Nordenskjöld) Formation (Longing Gap, Graham Land), respectively. Stratigraphically important macrofossils (ammonites, aptychi, belemnites, bivalves) as well as microfossils (radiolarians) were found in the same sections and sometimes even in the same samples.

The ammonite fauna in the sequences is mainly composed of cosmopolitan or Tethyan elements showing no significant differences from Tethyan or other eastern Pacific sites on a genus level. Hence, ammonites allow a fairly straightforward chronostratigraphic assignment.

The excellently preserved radiolarian faunas recovered from carbonate concretions exhibit a pronounced Austral aspect (Kiessling & Scasso 1996). Nevertheless, they can be linked to the North American standard zonation (Pessagno *et al.* 1993, 1994) and allow a detailed biostratigraphic subdivision. However, the chronostratigraphic radiolarian ages are always in slight disagreement with ammonite ages.

In this paper we provide a revised chronostratigraphic assignment of the Kimmeridgian/Tithonian North American radiolarian zones established by Pessagno *et al.* (1984, 1987b, 1993) and evaluate the applicability of other radiolarian zonations in Antarctica.

GEOLOGICAL SETTING

The Antarctic Peninsula formed a separate plate which was situated in southern high latitudes during Late Jurassic time (see review in Kiessling & Scasso 1996).

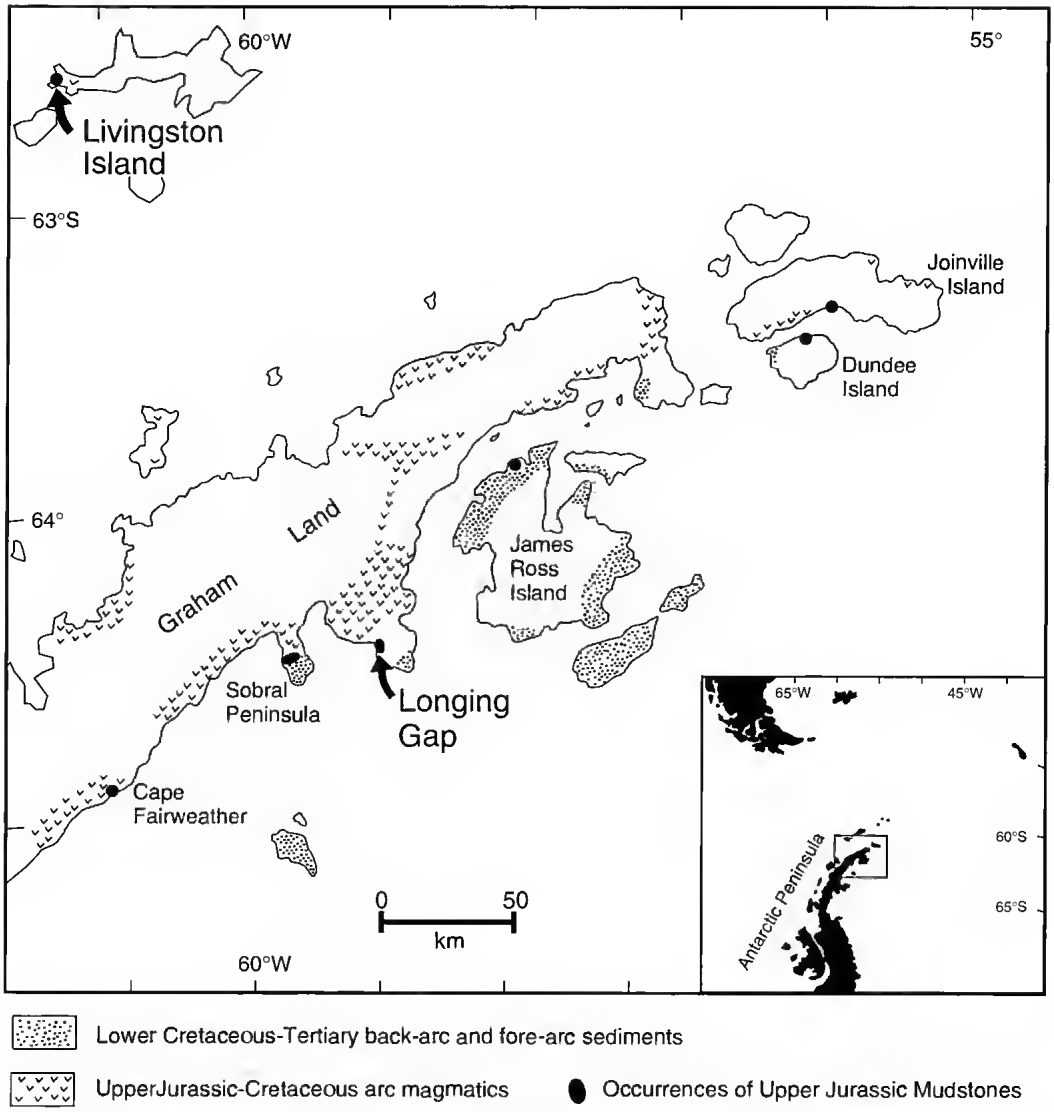

FIG. 1. — Geological map of the northeastern Antarctic Peninsula (Graham Land). The studied localities are printed in bold.

This region is characterized by an almost continuous magmatic activity from the Early Jurassic to the Miocene (Barker *et al.* 1991; Leat & Scarrow 1994), similar to the southernmost Andes. During the Jurassic period, the eastward subduction of the Pacific Phoenix Plate led to the development of a calc-alkaline magmatic arc (Antarctic Peninsula Volcanic Group) with volcaniclastic sequences in the fore-arc and back-arc areas. The magmatic arc is thought to have formed partly on pre-existing continental crust (Hervé *et al.* 1996).

Back-arc of the Antarctic Peninsula volcaniclastic sediments and anoxic radiolarian-rich mudstones are supposed to unconformably overlay an older accretionary complex, the Trinity Peninsula Group. The mudstone sequence belongs to the mainly Upper Jurassic Ameghino Formation (Medina & Ramos 1981; Medina *et al.* 1983) also known as Nordenskjöld Formation

(Farquharson 1982, 1983) which forms the basal sedimentary infill of the Larsen Basin in the northeastern Antarctic Peninsula (Macdonald *et al.* 1988). The basin contains approximately 6000 m of epi- and volcaniclastic sediments deposited from the Late Jurassic to the Paleogene. Outcrops of the Ameghino Formation are scattered along the eastern coast of Graham Land (Fig. 1). They are either isolated by surrounding ice-masses or found in complex tectonic contact to other rocks.

The Late Jurassic Anchorage Formation is the chronostratigraphic equivalent of the Ameghino Formation in the fore-arc region (Pirrie & Crame 1995). As in the Ameghino Formation mudstones and tuffs prevail, but additional sandstone beds are intercalated. The Anchorage Formation forms the base of a 1000 m thick sequence (Byers Group) ranging from the Kimmeridgian to the Valanginian (Crame *et al.* 1993). The Anchorage Formation is only exposed on Byers Peninsula, Livingston Island.

LOCALITY DESCRIPTIONS

Longing Gap

Longing Gap is situated at the Nordenskjöld Coast (Larsen Inlet) of northern Graham Land (Fig. 1). The area without permanent ice cover extends some 4 km in a north-south direction and a maximum of 1.5 km in an east-west direction (Fig. 2) and is surrounded by glaciers. Longing Gap is the type locality of the Ameghino Formation and only rocks assigned to the Ameghino Formation are exposed there. The geological structure is a wide syncline with a nearly east-west oriented axis. Beds dip to the south at the northern margin of the exposure; they lie horizontal in the southern part, and dip gently to the north at the southernmost margin. Minor faults are present, but no significant offset was noticed.

The sedimentary succession consists of black mudstones and gray tuffs. Both lithologies are tightly intercalated or mixed. Additionally, calcite concretions are common throughout the section reaching 3 m in diameter. They occur in mudstones as well as in tuffs, but mudstone concretions are generally larger. At the base of the succession mudstones predominate, while towards the top tuff beds become increasingly abundant. This trend led Whitham & Doyle (1989) to distinguish two members: a lower Longing Member and a higher "Ameghino" Member. Although there is a continuous transi-

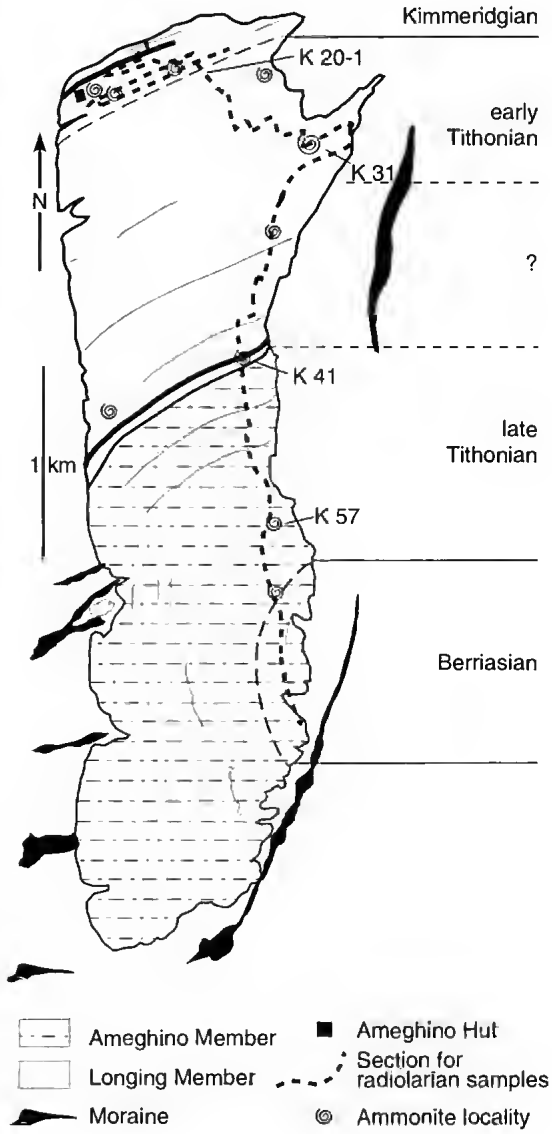

FIG. 2. — Outcrop of the Ameghino Formation at Longing Gap. The profile line for radiolarian samples, important concretion levels and ammonite locations, and the ages provided by ammonites are indicated.

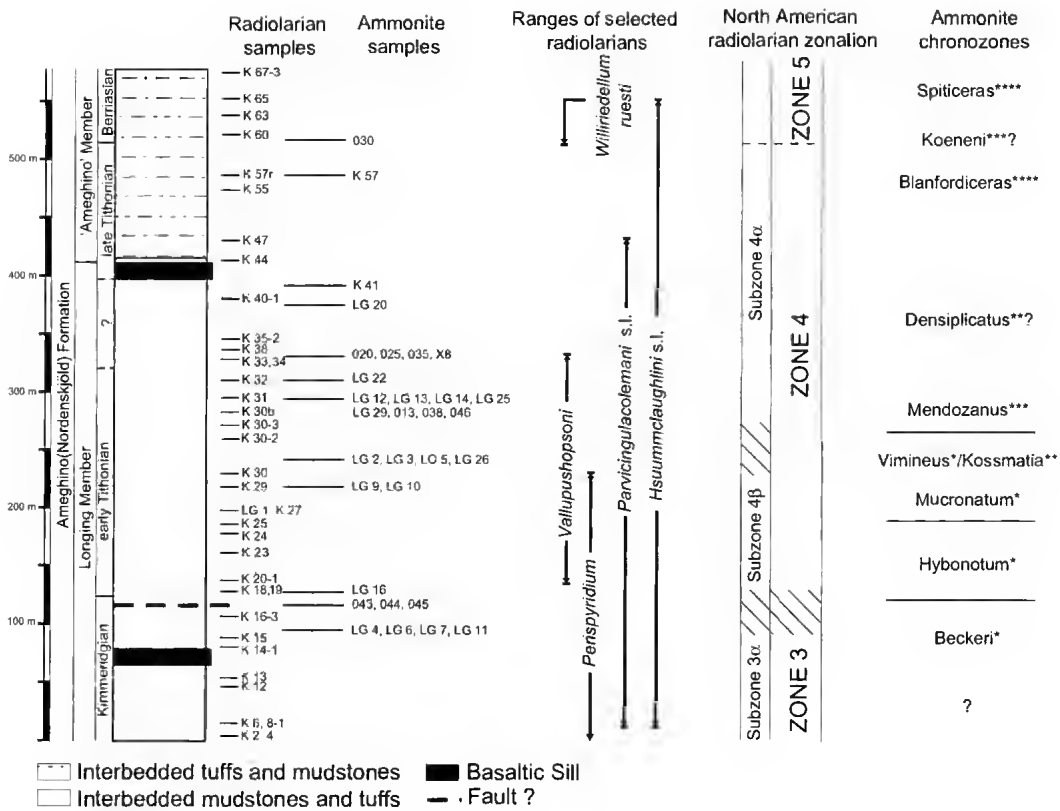

FIG. 3. — Idealized lithological column of the Ameghino Formation at Longing Gap. Important radiolarian samples, ammonite localities, selected ranges of radiolarian taxa, radiolarian zones and preliminary ammonite zones are shown. Ammonite samples from transported blocks are indicated by a question mark. CrossStars after ammonite zones indicate: *, European standard zone; **, Himalayan zone; ***, Argentinean zone; ****, Antarctic zone. Due to the problems in recognizing middle Tithonian, we subdivide the Tithonian *sensu* Gallico.

tion, the division proposed by these authors is followed in this paper. Owing to the relatively poor exposure quality of the succession it is difficult to determine the total thickness. Whitham & Doyle (1989) have estimated a thickness of 450 m for the Ameghino Formation at Longing Gap, but Scasso & Villar (1993) mention 600 m. New geodetic results from our field campaign (Santisteban 1997) indicate a total thickness of 580 m. The lower Longing Member is 420 m thick, whereas the upper "Ameghino" Member is 160 m thick (Fig. 3).

The black mudstones in both members are laminated or structureless. The tuffs are often graded and show undulate bases due to loading. The tuff layers are interpreted as pelagic deposits of air-fall ashes, related to single volcanic events (Whitham 1993). Intense silicification is frequent (Scasso *et al.* 1991). Mudstones as well as tuff beds are laterally continuous. Current sedimentary structures are rare and no influence of (storm) wave activity is evident. Slumps are very rare and small.

The depositional environment of the Ameghino Formation is assigned to an anoxic to dysoxic basin, according to Farquharson (1983), Doyle & Whitham (1991) and Whitham (1993). Anoxic conditions prevailed especially in the Longing Member; this is indicated by the often lacking bioturbation and rare horizons with benthonic fossils as well as by geochemical indicators (Scasso & Villar, 1993). In the "Ameghino" Member moderately intense bioturbation (*Zoophycos*, *Chondrites*, *Planolites*) and a conse-

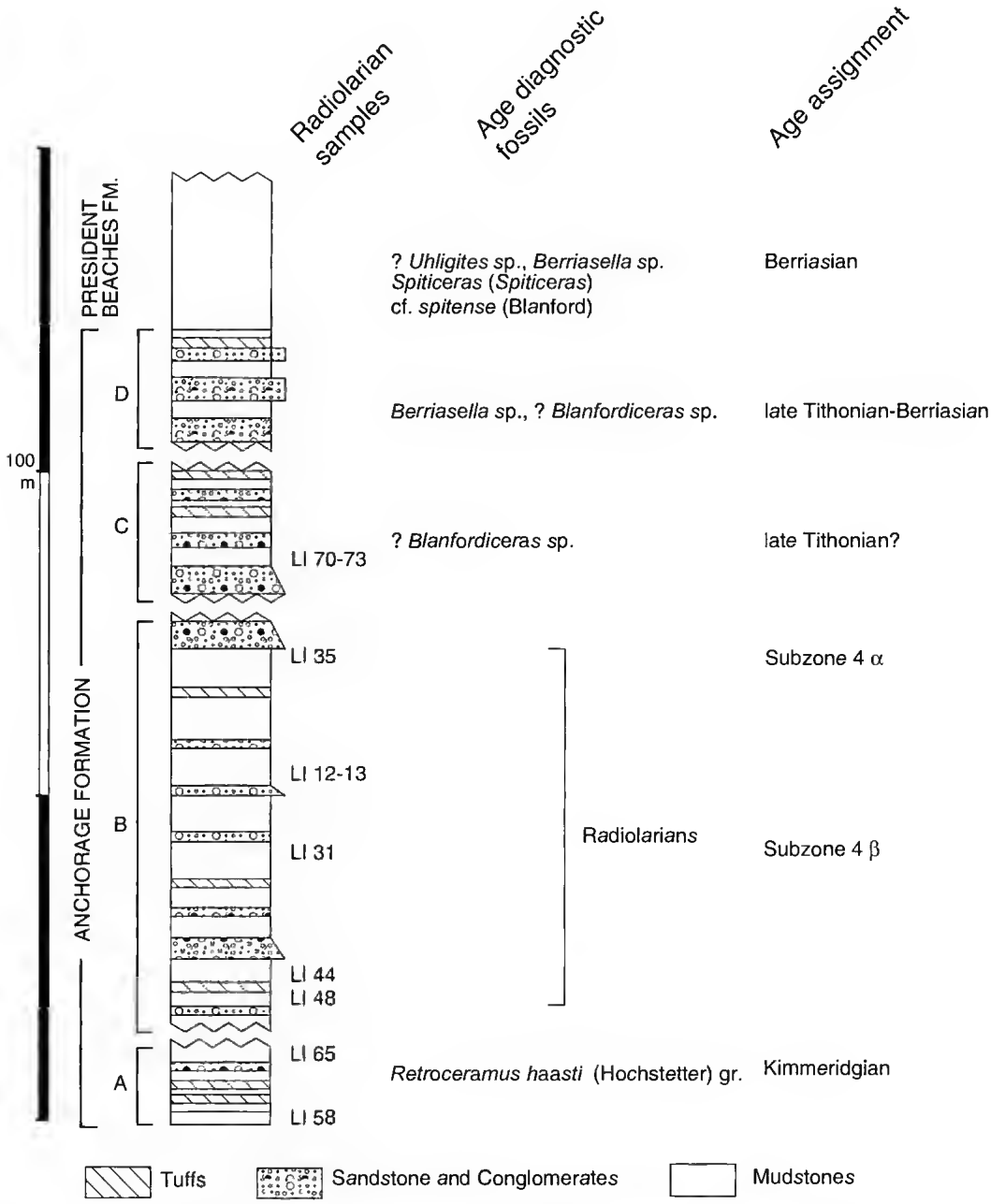

FIG. 4. — Idealized composite section of the Anchorage Formation on Byers Peninsula (Livingston Island). Only radiolarians from Zone 4 could be recovered. Macrofossil ages are based on fauna collected by Crame *et al.* (1993) at the base and own data for the higher part of the section. The late Tithonian age for the upper part of the Anchorage Formation is based on new findings of *Blanfordiceras* sp. and *Berriasella* sp.

quent destruction of lamination indicate dysaerobic conditions.

The Longing Member is more poorly exposed than the "Ameghino" Member. Only about one fourth of the Longing Member is exposed in place, whereas more than half of the "Ameghino"

Member is well exposed. However, with the exception of some small displacements due to cryoturbation, most of the loose blocks forming the scree cover can be considered in place. This is indicated by weathered carbonate concretions that are perfectly traced in the scree. Therefore, it was possible to get a complete section of the Ameghino Formation at Longing Gap.

The sequence contains common macrofossils (ammonites, belemnites, bivalves, aptychi, fishes, driftwood) allowing a stratigraphic subdivision. We emphasize on ammonites in this paper. Although the microfauna is diverse as well (radiolarians, sponge spicules, foraminifera, palynomorphs), we exclusively refer to radiolarians herein. The ammonites, like most other macrofossils, are particularly enriched in certain horizons, which are often widely separated. Radiolarians are only well preserved in carbonate concretions. However, the concretions are continuously distributed in the Longing Gap Section. As a consequence the radiolarian documentation is more continuous than the ammonite documentation.

Byers Peninsula

The Anchorage Formation was defined by Crame *et al.* (1993). It is composed of dark gray to black mudstones interbedded with sandstones and tuffs. Its true boundaries have not been observed. Although it is separated from the overlaying Betriasian President Beaches Formation by a fault, facies analysis indicates a transitional change between this two units.

Detailed mapping (Lopetrone 1997) allowed the recognition of several Anchorage Formation outcrops in fault-bounded blocks showing different facies associations. Crame *et al.* (1993) suggested a minimum thickness of the composite section of 105 m. A composite section quite different and difficult to match with the one of Crame *et al.* (1993) resulted from our work (Fig. 4), probably as a consequence of the structural complexity of the area. The integrated thickness of the Anchorage Formation is close to 120 m including an uppermost sequence transitional to the President Beaches Formation.

The whole sequence is composed of radiolarian-rich mudstones with intercalations of tuffs and – in contrast to the Ameghino Formation – sandstone beds (see Pirrie & Crame 1995, for a detailed description). The sandstone beds reach up to 80 cm in thickness and show evidence of turbiditic sedimentation. Carbonate concretions occur throughout the section. However, they are smaller than at Longing Gap and many are silicified. As in the Ameghino Formation there is a shift from parallel-laminated to intensely bioturbated mudstones within the sequence.

Our composite section is composed of four intervals. The lowermost exposure is about 11 m thick. It is separated from the middle part by a fault with uncertain offset. This middle part is about 55 m thick. A one meter thick conglomerate occurs at the top of this part of the section. The upper two parts of the section reach a composite thickness of around 50 m and are predominated by sandstones and conglomerates.

In contrast to Longing Gap, age diagnostic macrofossils are relatively rare on Byers Peninsula. Driftwood, bivalves, belemnites, and a few ammonites could be recovered. The carbonate concretions bear very well preserved radiolarian faunas in the middle section.

FAUNAL CHARACTERISTICS

Owing to the high paleolatitude of the Antarctic Peninsula the fossils are expected to show biogeographical differences as compared with lower paleolatitude sites. Since paleobiogeography has some impact on stratigraphic correlation we shortly discuss biogeographical affinities of both ammonites and radiolarians below.

Ammonites are affected by the high latitude depositional environment by their reduced diversity and some morphological modifications. With the probable exception of *Blanfordiceras*, all Antarctic genera are to be found in Tethyan sections as well. There is no striking evidence for an Austral ammonite province in the Tithonian which could be equivalent to the Northern Hemisphere Boreal provinces (Callomon in Hillebrandt *et al.* 1992, but see also Enay & Cariou 1997).

In contrast, the radiolarians display a pronounced Austral aspect, both in the Ameghino

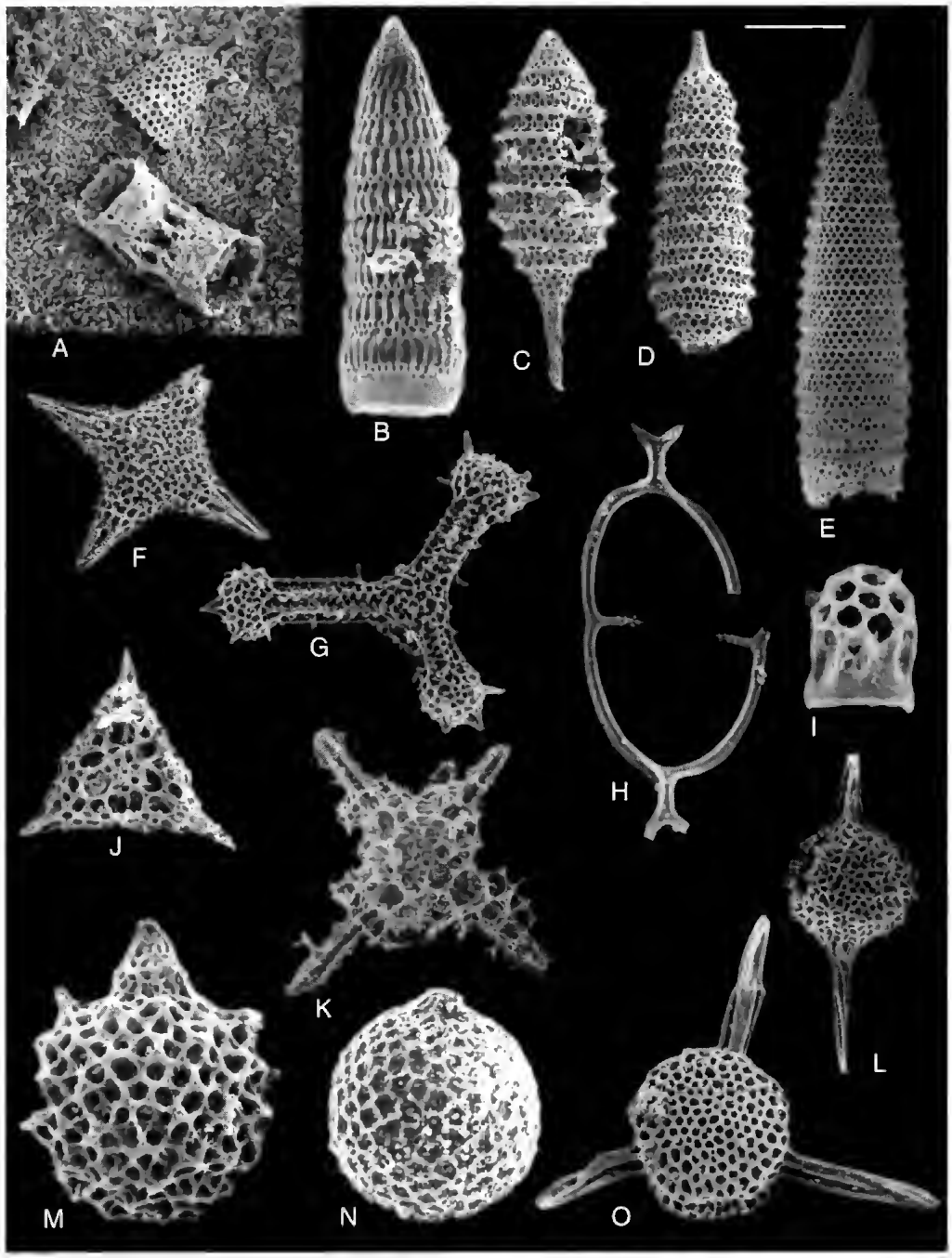

FIG. 5. — Age diagnostic radiolarians from Byers Peninsula (LI) and Longing Gap (K, LG). **A**, *Bivallupus mexicanus* Pessagno & MacLeod, etched concretion cut parallel to bedding (K 20-1); **B**, *Loopus primitivus* (Matsuoka & Yao) (LI 31); **C**, *Tethysetta boesii* gr. (Parona) (K 44); **D**, *Parvicingula colemani* Pessagno & Blome (K 25); **E**, *Parvicingula excelsa* Pessagno & Blome (LG 1); **F**, *Crucella theokattensis* Baumgartner (K 14-1); **G**, *Tritrabs rhododactylus* Baumgartner (LI 31); **H**, *Acanthocircus furiosus* Jud (LI 31); **I**, *Vallupus hopsoni* Pessagno & Blome s.l., very small specimen (LI 44); **J**, *Perispyridium ordinarium* (Pessagno) gr. (K 6); **K**, *Hallodictya* (?) *antiqua* (Rüst) s.l. (K 14-1); **L**, *Acaeniotyle parva* Yang = *Acaeniotyle umbilicata* (Rüst) gr. (K 13); **M**, *Sethocapsa trachyostraca* Foreman (K 13); **N**, *Gongylothorax favosus* Dumitrica (K 4); **O**, *Suna echiodes* (Foreman) s.l. (LI 13). See Kiessling (1999) for figures of additional age diagnostic radiolarians. Scale bar: A, 76 µm; B, I, M, N, 50 µm; C-H, J-L, O, 100 µm.

Formation and in the Anchorage Formation. The faunas exhibit typical high latitude characteristics as indicated by the predominance of *Parvicingula/Praeparvicingula* (Fig. 5D, E). The Antarctic faunas are especially similar to the Southern Boreal Province as defined by Pessagno & Blome (1986), Pessagno *et al.* (1993), and Hull (1997). Both the Austral Province and the Southern Boreal Province have many species in common and share features such as the fluctuating pantanelliid abundance and the high diversity of *Parvicingula* (Hull 1995; Kiessling 1999). Compared with faunas from equivalent latitudes on the Northern Hemisphere, Pantanelliidae are considerably more abundant (Kiessling & Scasso 1996). Typical Tethyan taxa such as *Tritrabs* and *Podocapsa* are rare but present. *Vallupus hopsoni* and other vallupins are present, which is very useful for stratigraphic correlation. *Hsuum* and *Perispyridium* are as common as in Tethyan sections and can also be used for global correlations. However, the stratigraphically important Tethyan taxa *Mirifusus*, *Ristola*, and *Acanthocircus dicranacanthos* (Squinabol) are totally absent in Antarctica which limits the correlation with Tethyan sections.

A selection of stratigraphically important radiolarians is shown in Figure 5. A more comprehensive taxonomic framework is provided by Kiessling (1999).

STRATIGRAPHY

Former ammonite and bivalve data suggested an age range of Kimmeridgian/early Tithonian to late Tithonian/Berriasian for the investigated sections (Whitham & Doyle 1989; Crame *et al.* 1993; Pirrie & Crame 1995). Our new material is essentially in agreement with previous designations, but we are now able to provide a more detailed stratigraphic subdivision.

The first stratigraphic subdivision of the Longing Gap Section based on radiolarians was proposed by Kiessling & Scasso (1996) and Kiessling (1996). Referring to the North American standard zonation the authors came to the conclusion that the age range of the Ameghino Formation is early Tithonian to Berriasian. Our new material shows that although the radiolarian zonation of the sequence is still valid, the chronostratigraphic calibration needs to be revised.

The discussion of ammonite ages relies on comparisons with Antarctic, Argentinean, European, and Himalayan zonations, whereas the radiolarian zones are first exclusively compared with the North American zonation of Pessagno *et al.* (1984, 1987, 1993, 1994) and Hull (1997).

STRATIGRAPHY OF LONGING GAP

Ammonites (A. Zeiss and A. C. Riccardi)

The first ammonite from Longing Gap, a Late Jurassic *Perisphinctes* sp., was mentioned by Bibby (1966). Further investigations were undertaken by Medina & Ramos (1981, 1983), Thomson (1982), Farquharson (1983), Medina *et al.* (1983), Zeiss (manuscript 1985), Whitham & Doyle (1989), and Doyle & Whitham (1991). New material was collected during the Argentinean Antarctic field campaign (1993/1994) by Scasso, Santisteban and Kiessling. Most ammonites are difficult to identify, as incomplete and crushed specimens prevail; often only impressions of crushed ammonites are available. Therefore, many determinations are obtained not with the same security as from better preserved material; this should be kept in mind when using the determinations below.

From base to top we can identify the following macrofossils (horizons are numbered according to the closest concretion level, Fig. 3):

K 16 [LG 11]. *Virgataxioceras* cf. *setatoides* (Berckhemer & Hölder) (Fig. 6F): the impression of a crushed perisphinctid ammonite with relatively coarse ribs. Ribs predominantly bifurcating, but sometimes trifurcating ("polygyrate"). The ribbing style resembles somewhat that of *"Perisphinctes" uracensis* (Berckhemer & Hölder, 1959, pl. 7/35), but the ribs are branching a little deeper near the middle of the flanks and the secondaries are somewhat more inclined. Thus, the specimen fits better to a paratype of *Virgataxioceras setatoides* (Berckhemer & Hölder 1959, Fig. 30).

K 16 [LG 4]. *Virgataxioceras* cf. *setatoides* (Berckhemer & Hölder): an impression of a crushed *Virgataxioceras*. The specimen is rather close to *Virgataxioceras setatoides* (Berckhemer &

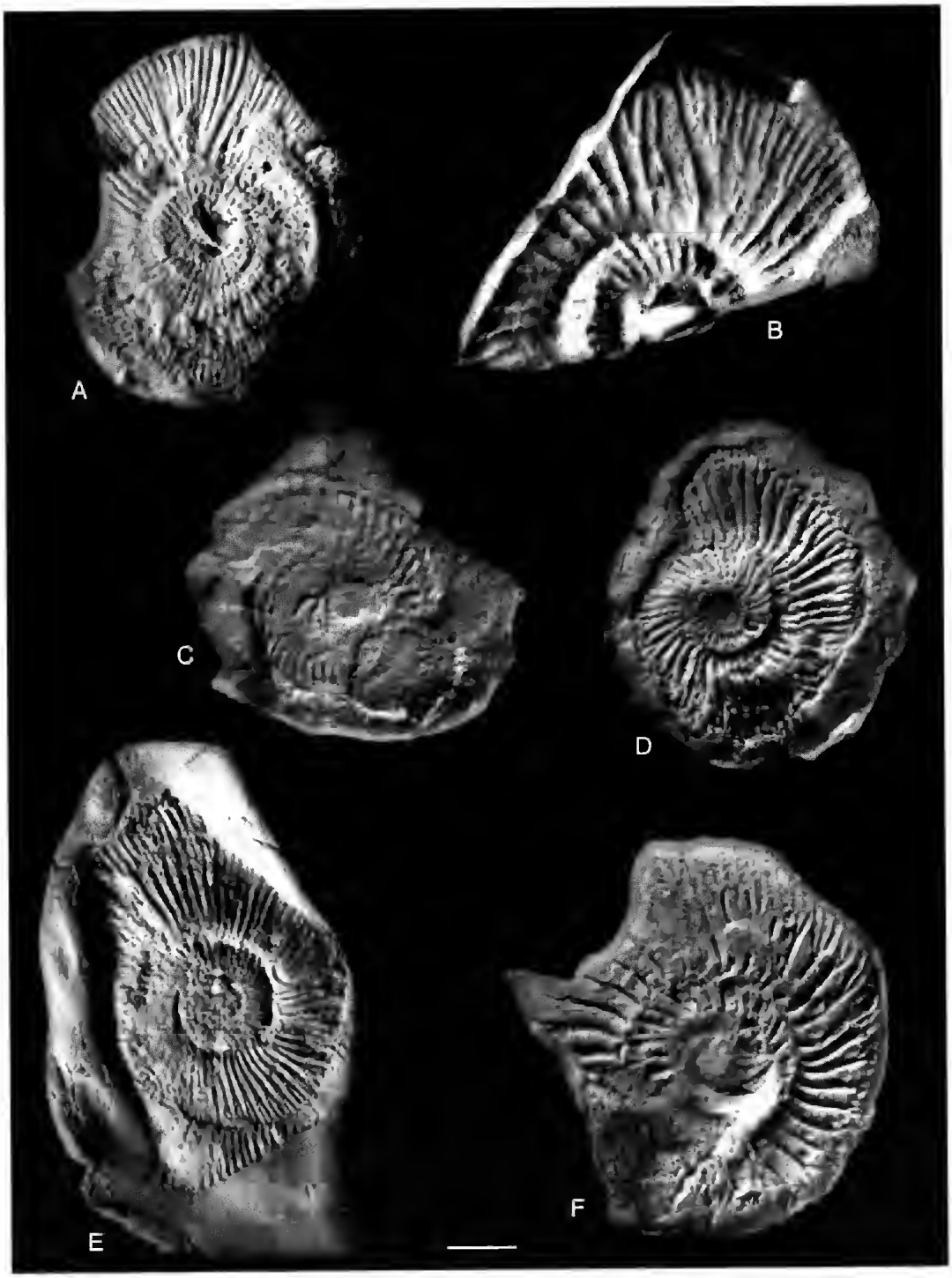

Fig. 6. — Age diagnostic ammonites from Longing Gap. **A**, ? *Virgatosphinctes densistriatus* (Steuer) (LG 20); **B**, *Virgatosphinctes* aff. *australis* (Burckhardt) (LG 25); **C**, *Taramelliceras* cf. *prolithographicum* (Fontannes) [LG 16(1)]; **D**, *Aulacosphinctoides* (?) sp. juv. [LG 16(2)]; **E**, *Subplanitoides* cf. *oppeli* Zeiss [LG 9(2)]; **F**, *Virgataxioceras* cf. *setatoides* (Berckhemer & Hölder) (LG 11). Scale bar: 1 cm.

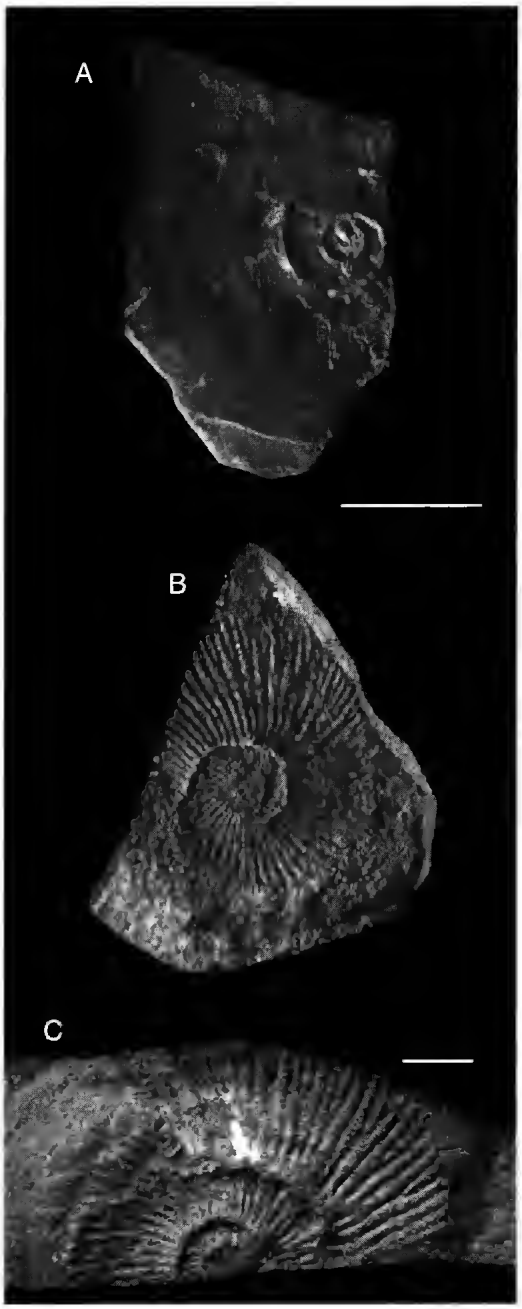

FIG. 7 — Age diagnostic ammonites from Longing Gap **A**, *Neochetoceras* (?) sp. [LG 9(1)]; **B**, *Kossmatia* (?) cf. *tenuistriata* (Gray) (LG 3); **C**, *Virgatosphinctes alternecostatus* (Steiger) (LG 29). Scale bars: 1 cm.

Hölder 1959, fig. 31). The shape and the ribbing style agree well. Differences are indicated by the somewhat more rigid recticostate and denser ribbing as well as by the branching point of the ribs situated a little deeper on our specimen.

K 16 [LG 6]. ?*Virgataxioceras* cf. *setatoides* (Berckhemer & Hölder): a rather poorly preserved specimen. Considering shape and ribbing style it seems to belong to the above described species or to a related late Kimmeridgian perisphinctid. A similar specimen has been described from the Antalo Limestone of Ethiopia (Jordan 1971).

K 17 [043]. *Glochiceras percevali* (Fontannes); *Glochiceras* cf. *lithographicum* (Oppel); *Taramelliceras* n. sp., aff. *prolithographicum* (Fontannes); *Torquatisphinctes habyensis* Spath; *Lamellaptychus lamellosus* (Parkinson): this sample contains a new species of the *Taramelliceras prolithographicum/Glochiceras lithographicum* group. The peculiar ribbing on the flanks of a large specimen is rather similar to *Taramelliceras hemipleura*, while overall morphology, ribs, and nodes of the outermost part of the flanks and the marginal and ventral region are well comparable with stronger ribbed variants of the *T. prolithographicum/G. lithographicum* group.

A similar, but smaller species of the same group is *T. flandrini* (Collignon 1960, pl. 147, fig. 583) from the early Tithonian of Madagascar. That species has a wider umbilicus, is stronger ribbed and shows no nodes in the center of the external side.

K 17 [044]. *Katroliceras* sp., *Retroceramus* cf. *haasti* (Hochstetter).

K 18 [045]. *Torquatisphinctes* sp.

K 18 [LG 16(1)]. *Taramelliceras* cf. *prolithographicum* (Fontannes) (Fig. 6C): an impression of a partly preserved *Taramelliceras*. The outer part of the flanks is well observable. These are ornamented with falcate ribs. The inner part of the ribs is not strongly curved, the outer part is curved forward. The ribs bifurcate occasionally. The ends of the ribs are marked by small tubercles. A row of tubercles is also observed on the venter. The ribbing style is characteristic for *Taramelliceras prolithographicum* (Fontannes). However, as we cannot observe the inner parts of the flanks and the specimen is not complete, we determine it as *Taramelliceras* cf. *prolithographicum*.

There is some affinity to *T.* cf. *rigidum* as figured

by Medina *et al.* (1983, pl. 2e), but this determination does not agree with the description of the species by Hölder (1955) and his illustration of the holotype.

K 18 [LG 16(2)]. *Aulacosphinctoides* (?) sp. juv. (Fig. 6D): this small specimen is difficult to identify, as young specimens of the genera *Aulacosphinctoides*, *Katroliceras* and *Torquatisphinctes* can be very similar and only the cross-section could help to distinguish them (cf. Spath 1931). However, there is a rather good correspondence between the shape of our specimen and those of young *Aulacosphinctoides* as figured by Spath (1931, pls 78/4, 79/7). Bearing in mind the problems mentioned above, specimen is best identified as *Aulacosphinctoides* (?) sp. juv.

K 29 [LG 9(1)]. *Neochetoceras* (?) sp. (Fig. 7A): a rather well-preserved fragment of a compressed oppeliid with narrow umbilicus. The poor preservation of the suture does not allow to decide if the specimen belongs to the *Haploceras subelimatum* group. As the overall shape is that of *Neochetoceras* (see Oppel 1863, pl. 69/3), this specimen can be assigned to *Neochetoceras* (?) sp.

K 29 [LG 9(2)]. *Subplanitoides* cf. *oppeli* Zeiss (Fig. 6E): an impression of a densely ribbed perisphinctid fragment. A cast of the specimen is very close to *Subplanitoides oppeli* Zeiss (1968, pl. 8/2). As the venter is not observable a determination as *Subplanitoides* cf. *oppeli* is justified.

K 29 [LG 10, LG 27]. *Neochetoceras* (?) sp.: several oppeliid specimens, crushed. Similar forms have been figured by Whitham & Doyle (1989, fig. 6e). They agree in shape with *Neochetoceras*. In order to exclude the possibility that they belong to *Pseudolissoceras*, the poorly preserved remains of suture-lines were closely observed. In the end we are convinced that the sutures suggest an assignment to *Neochetoceras* rather than to *Pseudolissoceras*.

?K 29 [LG 28]. *Glochiceras* sp.: another oppeliid specimen. The wider umbilicus suggests an assignment to *Glochiceras* rather than to *Neochetoceras*.

K 30 [LG 3]. *Kossmatia* (?) cf. *tenuistriata* (Gray) (Fig. 7B): fragment of a small ammonite. The ribbing is rather fine and dense. The branching point is situated in the upper part of the flanks. On the inner part of the last whorl the secondaries are bent forward. At the end of the shell the specimen is somewhat damaged and the bend is not well preserved. The determination of such a small specimen is difficult, especially when the ventral side can not be inspected. Some affinity exists to similar densely ribbed forms like *Kossmatia* aff. *tenuistriata* Gray (Thomson 1983, fig. 3g) or some *Virgatosphinctes* of the *tenuilineatus-burckhardti* group (cf. Indans 1954, pl. 13/1, 4). There is also some resemblance to the inner whorls of a "*Lithacoceras* sp.", as figured by Whitham & Doyle (1989, fig. 6g). Judging from the ribbing on the outer whorl, the form of Whitham & Doyle does not belong to *Lithacoceras*, but more likely to forms like *Franconites tenuiplicatus* Zeiss (1968, pl. 11/4). *Paraberriasella blondeti* Zeiss (1968, pl. 12/2) is also comparable to our form, but exhibits a different development of ribs on the outer whorl. All these forms come from the upper part of the lower Tithonian. The determination as *Kossmatia* (?) cf. *tenuistriata* is therefore only one of several other possibilities.

K 31 [013, 038a-e, 046, LG 12, LG 14, LG 25, LG 29]. A 1 m thick bank with abundant ammonites: ? *Aulacosphinctoides* sp.; *Haploceras* sp.; Oppeliidae indet.; ? *Taramelliceras* sp.; *Substreblites* or *Uhligites* aff. *kraffti* (Uhlig); *Virgatosphinctes* cf. and aff. *andesensis* (Douvillé); *Virgatosphinctes* sp.; *Virgatosphinctes* (*Lithacoceras*) sp.; *Lamellaptychus* cf. *lamellosus* (Parkinson); *Virgatosphinctes alternecostatus* (Steiger); *Virgatosphinctes* aff. *australis* (Burckhardt).

[013]. ? *Substreblites* or *Uhligites* aff. *kraffti* (Uhlig): a specimen of 47 mm in diameter, very involute and with fine falcoid ribbing. It looks like the specimens figured by Thomson (1979, pls 2/q, 3/d, f) under the above mentioned names. However, determination is doubtful since the venter could not be observed and the ribbing is stronger.

[LG 29]. *Virgatosphinctes alternecostatus* (Steiger) (Fig. 7C): half of the ammonite is preserved. The ribbing style is similar to *V. denseplicatus rotunda* (Spath 1931, pl. 96/2), but the umbilicus is more narrow. In this respect "*Perisphinctes*" *alternecostatus* Steiger (1914, pl. 104/1) fits better. This species seems to belong to *Virgatosphinctes* representing an intermediate form between the

denseplicatus and *communis* group.

[LG 25]. *Virgatosphinctes* aff. *australis* (Burckhardt) (Fig. 6B): a fragmentary specimen of *Virgatosphinctes* with a rather narrow umbilicus, but with more distant, polygyrate and bifurcate ribs (cf. Indans 1954, pl. 20/6).

K 32 [LG 22, K 32]. *Subdichotomoceras* sp.; ? *Virgatosphinctes* sp.

K 34 [020, 025, 035, X8]. *Virgatosphinctes* ["*Lithacoceras*" Indans] sp.; *Aulacosphinctoides* (?) cf. *patagoniensis* (Favre *in* Tavera); *Buchia* cf. *hochstetteri* (Fleming); *Buchia* sp.

[025]. *Aulacosphinctoides* (?) cf. *patagoniensis* (Favre *in* Tavera): a fragment of a rather large perisphinctid. The bifurcation point is changing in height between the inner third and the outer third of the flanks on the penultimate and outer whorl. Ribs on inner whorl split up in half to two thirds of the height of the flanks. There is no virgatotome or polygyrate splitting of the ribs. Single ribs are intercalated especially on the outer half of the penultimate and on the last whorl.

Since the specimen is fragmentary the assignment to *Aulacosphinctoides* remains questionable. A designation to *Torquatisphinctes* could also be possible. There is some affinity to specimens figured as "*Blanfordiceras patagoniense*" (Favre) Feruglio by Tavera (1970, pl. 3/8). However, those forms are smaller, more coarsely ribbed, and the high outer whorl of our specimen is absent.

K 40-1 [LG 20]. ? *Virgatosphinctes densistriatus* (Steuer) (Fig. 6A): an impression of a densely ribbed, virgatosphinctid ammonite with a rather narrow umbilicus. It has a good counterpart in the specimen figured by Indans (1954, pl. 21/5) as *V. densistriatus* (Steuer), but there is also a distinct affinity to undescribed forms of *Catutosphinctes* Leanza & Zeiss (1992) from Zapala, Argentina.

K 41. ? *Kawhiasphinctes* cf. *antipodus* Stevens: a fragment, broken at about the level of midflanks or slightly above. Only the outer half of the flanks with straight and slightly prosiradiate ribs can be observed. Any probable bifurcation point of the ribs should be situated deeper. The flanks are similar to the outer flanks of *Kawhiasphinctes antipodus* Stevens (1997, pl. 32/3) or *Virgatosphinctes* aff. *denseplicatus* (Thomson 1979, pl. 14/a). However, the latter is more densely ribbed and does not fit well. The specimen is too poorly preserved for any more precise identification.

K 57. *Blanfordiceras* cf. *weaveri* Howlett: a specimen of 87 mm in diameter with an umbilicus of *ca.* 40 mm. The venter is not preserved; of the last whorl only one quarter is preserved. The ribbing is similar to that in specimens figured from Antarctica as *Blanfordiceras weaveri* by Howlett (1989, pl. 2/5, 7), but our form is more evolute and the ribbing is somewhat coarser. The same is true in comparison with the specimen figured by Krantz (1928, pl. 3/4) or Weaver (1930, pl. 3/356-357). The ribs divide above midflank and are widely spaced in the last quarter of the whorl as in "*Blanfordiceras wallichi*" Gray as figured by Steuer (1891-1892, pl. 16/1). There is also some similarity to *Blanfordiceras delgai* Collignon (1960, pl. 166/680).

[030]. *Substeuroceras* or *Parodontoceras* sp. The specimen is comparable to the one figured by Olivero *et al.* (1980, pl. 1/2) from James Ross Island. It is also similar to *Kossmatia carsensis* (Thomson 1975).

[A1]. *Blanfordiceras* cf. *weaveri* Howlett: this ammonite stems from a moraine deposit above the top of the section. The specimen is comparable with "*Beriassella subprivasensis*" Krantz (*in* Thomson 1979, pl. 7/i), which was included by Howlett in his new species *B. weaveri*. It is also similar to "*Berriasella behrendseni*" of Feruglio (1936, pl. 7/3-7, 9).

Stratigraphic subdivision based on ammonites

Medina & Ramos (1981) and Medina *et al.* (1983) described ammonites from Longing Gap that can be assigned to the early to middle Kimmeridgian. Our new material did not contain ammonites of this age.

In our section, the first horizons with ammonites occur some 80 m above the base (K 16, K 17). These levels belong to the late Kimmeridgian *Hybonoticeras beckeri* zone. The presence of this substage is also demonstrated by a specimen figured by Whitham & Doyle (1989, fig. 6c) as *Hybonoticeras* sp. This form appears to represent the microconch of a new species of *Hybonoticeras* (*Hybonotella*) which belongs to the group of

H. beckeri. The specimen of Whitham & Doyle can best be compared with the inner whorls of a macroconch figured as "*Hybonoticeras hybonotum*" by Collignon (1960, pl. 132/494) from the "Kimméridgien moyen" of Madagascar. However, the species and age assignment of Collignon cannot be affirmed.

The presence of Submediterranean taxa (*Virgataxioceras*, *Hybonoticeras*) in Antarctica may be astonishing. However, Zeiss (1971, 1979) has shown that these genera are widespread along the eastern part of Africa (Ethiopia-Tanzania). Those forms probably immigrated together with Indian taxa (cf. Howlett 1989) via the Malagassian seaway into the Antarctic Region.

The early Tithonian *Hybonoticeras hybonotum* zone is reached in concretion level K 18 as proved by characteristic *Taramelliceras* species. In the middle part of the Longing Member (K 29, K 30-1) the ammonites may correspond with the *Mucronatum* and *Vimineus* zones of Southern Germany. They are comparable with *Subplanitoides*, *Franconites* and to the Pacific genus *Kossmatia*.

Higher in the section, some 70 meters above the former ammonite horizon, we find a typical *Virgatosphinctes* fauna similar to that of the Argentinean Neuquén Basin (K 31-K 32). This fauna is assigned to the late early Tithonian *Mendozanus* zone in Argentina.

Virgatosphinctes is present up to level K 40-1. It should be noted that true middle Tithonian elements of South America (*Pseudolissoceras* and *Aulacosphinctes proximus*) have not been discovered in Longing Gap so far. Reports from other Antarctic localities are very doubtful, too. However, the Antarctic *Virgatosphinctes* fauna may also represent the middle Tithonian and reach up even until the earliest late Tithonian. The *Virgatosphinctes-Hildoglochiceras* assemblage of Spiti was assigned to the middle Tithonian by Krishna *et al.* (1982) and Enay & Cariou (1997) assigned their *Virgatosphinctes* assemblage to the late Tithonian. The latter is characterized by *V. denseplicatus* which is also known from Antarctica (Howlett 1989). It is especially remarkable that in the upper part of the *Virgatosphinctes* beds of Longing Gap (K 34-K 40) only densely ribbed forms predominate which do not branch up in more than three secondaries. The specimen of K 41 could be of middle or late Tithonian age (cf. Stevens 1997; Enay & Cariou 1997). We preliminarily assign the beds above K 32 to the earliest late Tithonian *Densiplicatus* zone. Further investigation are necessary to define the range of the *Virgatosphinctes* fauna more precisely in the Antarctic region.

The first occurrence of *Blanfordiceras* s.s. is noted in concretion level K 57 providing clear evidence for late Tithonian. On Alexander Island (Howlett 1989) the *Blanfordiceras* fauna includes *Lytohoplites weaveri*, a true *Lytohoplites*. Species of this genus have been found in Chile (Biro-Bagoczky 1984) in the *Corongoceras alternans* zone, the second zone of the late Tithonian in South America. It corresponds approximately with the zone of *Paraulacosphinctes transitorius* in Mediterranean Europe, i.e., the middle part of the late Tithonian. This is in agreement with Thomson (1979) and Howlett (1989) who considered the *Blanfordiceras* zone as part of the late Tithonian.

Some 30 m above K 57 follow beds that can questionably be correlated with the Argentinean *Substeuroceras koeneni* zone. We can suppose the Jurassic/Cretaceous boundary in these beds (cf. Zeiss 1986).

Near the top of the section a Berriasian age is suggested by *Spiticeras* (*Spiticeras*) according to Whitham & Doyle (1989).

North American radiolarian zones at Longing Gap

The base of the Longing Gap Section is assigned to Zone 3 as indicated by the presence of *Cameta hsui* (Pessagno) and the absence of *Vallupus hopsoni* Pessagno & Blome. Since neither *Turanta* s.s. nor *Hsuum maxwelli* Pessagno were found, we presume that the basal part of the Longing Gap Section belongs to upper Subzone 3 alpha, although the primary marker taxon *Napora burckhardti* Pessagno, Whalen & Yeh was not recorded (= exclusively Tethyan marker taxon according to Pessagno *et al.* 1987b). The secondary marker taxa *Parvicingula colemani* Pessagno & Blome (Fig. 5D) and *Hsuum mclaughlini* Pessagno & Blome are present near the base indicating Subzone 4 beta. However, the primary

marker taxon *Vallupus hopsoni* was not recorded, although pantanelliids and even vallupins are common in some samples and we have searched for this species intensely. The last distinct horizon before the evolutionary first appearance of *V. hopsoni* is K 14-1, K 15. Above those samples *V. hopsoni* is absent, but the scarcity of other pantanelliids indicates that its absence may be due to paleoceanographic factors.

The base of Zone 4-Subzone 4 beta is well defined by the first appearance of *Vallupus hopsoni* in sample K 20-1. This is noted just above the first Tithonian ammonites assigned to the *Hybonotum* zone. The first occurrence of *Vallupus hopsoni* provides the most reliable datum in the section. It will be discussed in detail below. Up section *V. hopsoni* is continuously present in samples with a high total pantanelliid abundance.

The top of Subzone 4 beta is marked by the last appearance of *Perispyridium* in concretion K 29. *Perispyridium* is represented by two new species within Subzone 4 beta (Kiessling 1999). It is continuously recorded in all better preserved assemblages. The last occurrence of *Perispyridium* is noted between ammonite assemblages assigned to the early Tithonian *Mucronatum* and *Vimineus* zones, respectively.

Marker taxa in Subzone 4 alpha and the suspected Zone 5 are rare. The base of Subzone 4 alpha is characterized by abundant Pantanelliidae including *Vallupus hopsoni* and the absence of *Perispyridium*. The last occurrence of *V. hopsoni* is noted some 20 m above the ammonite horizon that has been assigned to the late early Tithonian *Mucronatum* zone. The upper boundary of Subzone 4 alpha is poorly defined owing to the absence of primary marker taxa. It is preliminarily drawn between the last occurrence of *Parvicingula colemani* Pessagno & Blome and the first occurrence of *Williriedellum ruesti* (Tan Sin Hok).

The radiolarian ages are without major contradictions with regard to the zonation of Pessagno *et al.* (1993). However, the secondary and corporeal marker taxa *Parvicingula colemani*, *Parvicingula jonesi* Pessagno s.l. and *Hsuum mclaughlini* s.l. occur slightly earlier than predicted in Pessagno's zonation.

In summary, the Ameghino Formation at Longing Gap ranges from the Kimmeridgian to the early Berriasian. The Longing Member ranges from the Kimmeridgian to probably the earliest late Tithonian and the "Ameghino" Member is assigned to the late Tithonian to early Berriasian. The part of radiolarian Zone 3 exposed at Longing Gap (top of Subzone 3 alpha) can be assigned to the Kimmeridgian. The base of Zone 4 is likely to coincide with the base of the Tithonian or latest Kimmeridgian. The boundary between Subzone 4 beta and Subzone 4 alpha is assigned to the middle part of the early Tithonian (*sensu* Gallico). The boundary between Zone 4 and Zone 5 is less clearly defined at Longing Gap. The occurrence of *Spiticeras* (*Spiticeras*) approximately coincides with radiolarian assemblages preliminarily assigned to Zone 5. This would indicate that the boundary of Zone 4-Zone 5 agrees with the Jurassic-Cretaceous boundary. A more detailed discussion follows below.

Stratigraphic summary of Byers Peninsula

Radiolarians

No radiolarians could be extracted from the basal section, but the middle section yielded several exceptionally well preserved faunas (Figs 4, 8). Most of the productive samples can be assigned to Subzone 4 beta. This is confirmed by the co-occurrence of *Vallupus hopsoni* and *Perispyridium* near the base of the fertile sequence (LI 44). The overlying concretions lack Vallupinae (for paleoceanographic reasons) but contain *Perispyridium*, thus indicating Subzone 4 beta as well.

Near the top of the middle section, a well-preserved fauna (LI 35) contains *Vallupus hopsoni*, but lacks *Perispyridium*. This sample is, therefore, assigned to the base of Subzone 4 alpha.

No age diagnostic radiolarians could be extracted from the upper section.

Ammonites, belemnites and bivalves

First age diagnostic ammonites and belemnites from the Upper Jurassic sequence were listed by Tavera (1970) and Smellie *et al.* (1980). Smellie *et al.* (1980) found indication for Kimmeridgian (*Hibolites marwicki marwicki* Stevens and *Subplanites* sp.), early Tithonian (*Belemnopsis stoleyi* Stevens) and late Tithonian (*Berriasella* cf. *behrendseni* Burckhardt). Without referring to a

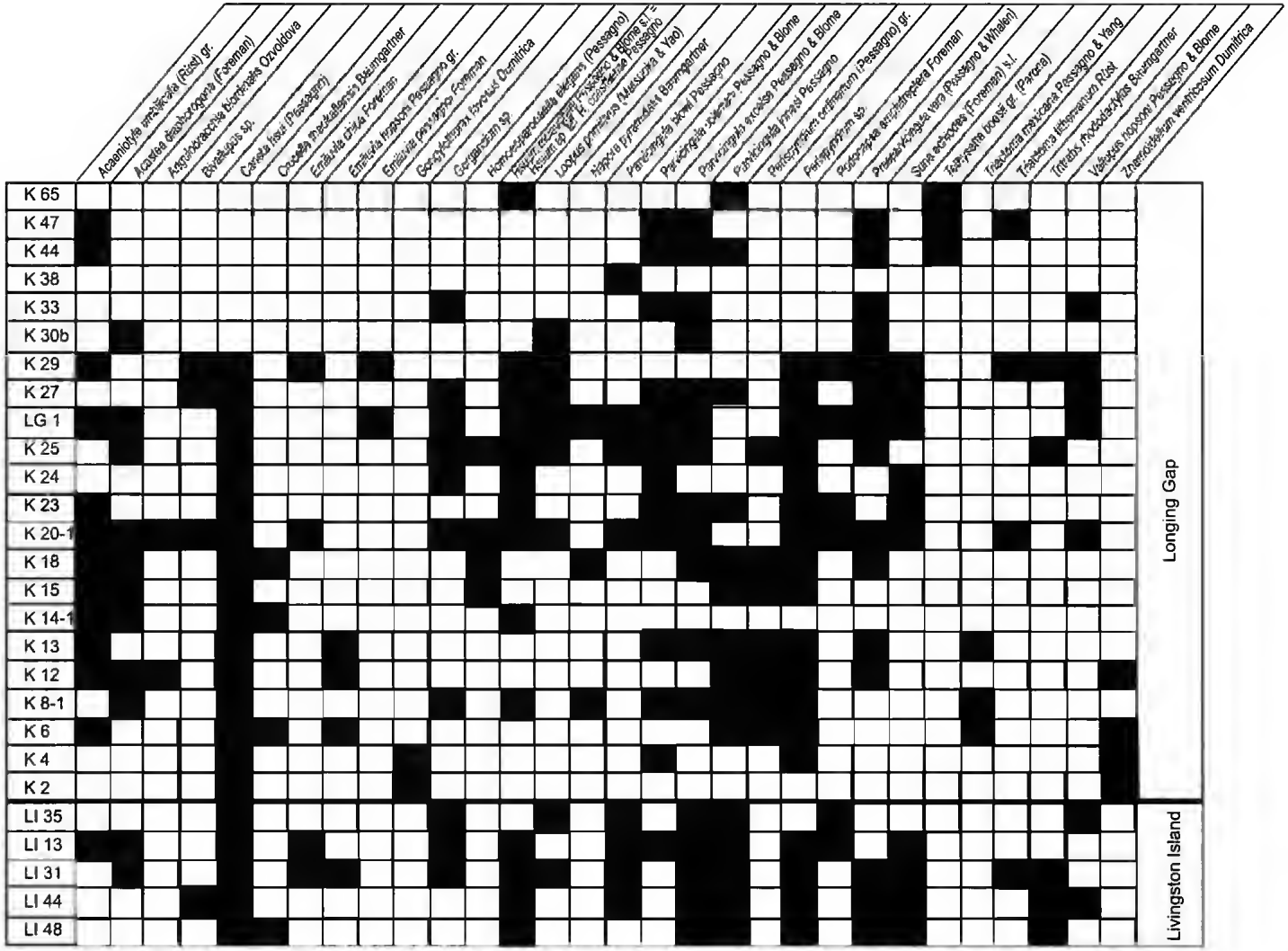

FIG. 8. — Occurrence of age diagnostic radiolarians discussed in the text. Only samples with good preservation and only taxa occurring in more than one sample are indicated. See text for single species occurrences.

section they gave a "balanced" age of early Tithonian for the "mudstone member".
Crame *et al.* (1993) found inocerams of the *Retroceramus haasti* (Hochstetter) group near the base of the section suggesting (but not proving) Kimmeridgian. Near the top of their section Crame *et al.* (1993) found an ammonite-belemnite assemblage with Tithonian affinities. We could collect *Berriasella* and ? *Blanfordiceras* 25 m below the upper boundary of the exposed sequence providing evidence for late Tithonian. *Spiticeras* (*Spiticeras*) cf. *spitense* (Blanford) was found in the overlaying President Beaches Formation. No ammonites were discovered in the radiolarian-rich interval.

In summary, the Anchorage Formation on Byers Peninsula ranges from Kimmeridgian/Tithonian to latest Tithonian. Radiolarians belonging to Subzone 4 beta are stratigraphically closer to what has been dated as Kimmeridgian than to the *Berriasella*-bearing late Tithonian/Berriasian (Fig. 4). The data support the conclusion that Subzone 4 beta should be completely assigned to the early Tithonian, although the evidence is less convincing than at Longing Gap.

LATE JURASSIC RADIOLARIAN BIOSTRATIGRAPHY

The biostratigraphic use of Late Jurassic radiolarians has only been recognized in the past twenty years starting with Pessagno (1977a). Since then a number of Late Jurassic radiolarian zonations have been proposed. There are basically four zonations in use for different regions of the world.

1. The North American zonation: this zonation dates back to the work of Pessagno (1977a). It was completely revised by Pessagno *et al.* (1984) and refined later by Pessagno *et al.* (1987b, 1993, 1994). The most recent update of the North American zonation was provided by Hull (1997). The chronostratigraphic calibration of radiolarian zones was established using ammonite, calpionellid and bivalve data.

2. The Tethyan zonation: a first zonation was presented by Baumgartner *et al.* (1980) based on unitary associations. This zonation was considerably revised by Baumgartner (1984), chronostratigraphically updated by Baumgartner (1987), and reached its current state by the comprehensive contribution of Baumgartner *et al.* (1995a). The chronostratigraphic calibration of radiolarian zones was established by using ammonite, calpionellid and calcareous nannofossil ages.

3. The "Japanese" zonations: several Japanese scientists developed zonations which are mostly applied to western Pacific sections, but are also useful in the Tethys. The most widely used zonation has been developed by Matsuoka & Yao (1986) which was updated by Matsuoka (1992, 1995b). The chronostratigraphic calibration is partly provided by ammonite and calcareous nannofossil data, but mostly relies on correlation with dated Tethyan and North American radiolarian-bearing sequences.

4. The Russian zonations: zonations of the Caucasus Region and the Russian Far East were proposed by Tikhomirova (1988) and Vishnevskaya (1993). The Jurassic zones in the Caucasus are calibrated by ammonites and aptychi, whereas the Russian Pacific margin is poorly dated by *Buchia* sp. Late Jurassic radiolarian stratigraphy on the Russian platform is still in its infancy with only one preliminary zonation available (Kozlova 1994).

As explained above, we mostly applied the North American radiolarian zonation for dating our radiolarian samples. The primary, secondary and corporeal markers of Pessagno *et al.* (1993) that are present in Antarctica are listed in Table 1. The application of the new Unitary Association stratigraphy of Baumgartner *et al.* (1995a) is hampered by the scarcity of Tethyan taxa. However, there are several species that have been used in Tethyan zonations as well (Table 1). The occurrences of species discussed below are indicated in Figure 8, if they were traced in more than one sample. Species occurring in only one sample are:

– LI 31: *Acanthocircus furiosus* Jud;
– K 8-1: *Saitoum pagei* Pessagno;
– K 12: *Protunuma japonicus* Matsuoka & Yao;
– K 13: *Sethocapsa trachyostraca* Foreman;

TABLE 1. — Antarctic radiolarian taxa used in published zonations.

Radiolarian marker taxa used in the North American zonation (Pessagno *et al.* 1984, 1987b, 1993, 1994)	Radiolarian species used in the Tethyan zonation (Baumgartner *et al.* 1995a)
Bivallupus	*Acaeniotyle umbilicata* (Rüst) gr.
Caneta hsui (Pessagno)	*Acanthocircus furiosus* Jud
Hsuum mclaughlini Pessagno & Blome s.l.	*Acastea diaphorogona* (Foreman)
Orbiculiforma lowreyensis Pessagno	*Angulobracchia biordinalis* Ozvoldova
Parvicingula blowi Pessagno	*Tethysetta boesii* gr. (Parona)
Parvicingula colemani Pessagno & Blome	*Crucella theokaftensis* Baumgartner
Parvicingula excelsa Pessagno & Blome	*Emiluvia chica* Foreman
Parvicingula jonesi Pessagno	*Emiluvia hopsoni* Pessagno
Praeparvicingula vera (Pessagno & Whalen)	*Emiluvia pessagnoi* Foreman
Perispyridium	*Gongylothorax favosus* Dumitrica
Tethysetta boesii (Parona)	*Haliodictya* (?) *antiqua* s.l. (Rüst)
Vallupus hopsoni Pessagno & Blome	*Homoeoparonaella elegans* (Pessagno)
	Hsuum sp. aff. *H. cuestaense* Pessagno (= *Hsuum mclaughlini* s.l.)
	Hsuum teliformis Jud
	Loopus primitivus (Matsuoka & Yao)
	Napora pyramidalis Baumgartner
	Perispyridium ordinarium (Pessagno) gr.
	Podobursa spinosa s.l. (Ozvoldova)
	Podocapsa amphitreptera Foreman
	Protunuma japonicus Matsuoka & Yao
	Saitoum pagei Pessagno
	Sethocapsa trachyostraca Foreman
	Suna echlodes (Foreman) s.l.
	Triactoma mexicana Pessagno & Yang
	Triactoma tithonianum Rüst
	Tritrabs rhododactylus Baumgartner
	Zhamoidellum ventricosum Dumitrica

– K 14-1: *Haliodictya*(?) *antiqua* (Rüst) s.l.;
– K 23: *Orbiculiforma lowreyensis* Pessagno;
– K 27: *Podobursa spinosa* (Ozvoldova) s.l.

We first discuss the value of the North American zonation and subsequently try to link our data to the zonation of Baumgartner *et al.* (1995a) and Matsuoka (1995b). The Russian zonations are not discussed, since their stratigraphic resolution is either too coarse or they consider poorly defined species.

THE NORTH AMERICAN RADIOLARIAN ZONATION

The major pitfall of the North American zonation is the reference to species absence in stratigraphic assignment. As zonal boundaries are defined by first or last occurrences of marker taxa, the reliability of their absence has to be critically evaluated for each section or sample. This can be achieved by observing the quantitative distribution of marker taxa within their range and by judging the possibility that species absence is merely a result of oceanographic, diagenetic or stochastic bias.

As discussed above, we can recognize the North American Zones 3 and 4, and probably zone 5 in Antarctica. Zone 3 was originally assigned to the early Tithonian, but it has been demonstrated by Baumgartner *et al.* (1995a) that its base may reach down to the middle Oxfordian.

The base of Zone 4 was originally (Pessagno *et al.* 1984, 1987) calibrated by corresponding closely to the first occurrence of *Crassicollaria intermedia* (Durand Delga) and late Tithonian ammonites in Mexico and by occurring below the *Buchia piochii* zone of Jones *et al.* (1969) in California.

TABLE 2. — Summary of modifications in the chronostratigraphic assignment of North American radiolarian zones resulting from our new data.

	Pessagno *et al.* (1977a, b, 1984, 1987, 1993)	This paper
Base of Zone 5	Tithonian/Berriasian boundary	Tithonian/Berriasian boundary?
Base of Subzone 4 alpha	early late/late late Tithonian boundary	Early Tithonian (Darwini zone)
Base of Zone 4	early/late Tithonian boundary	Kimmeridgian/Tithonian boundary

It was thus correlated with the early Tithonian/late Tithonian (*sensu* Gallico) boundary. Recently, this boundary was lowered to the late early Tithonian (Pessagno pers. comm. 1997; Hull 1997).

The new results from the Antarctic sections demand a revision of the chronostratigraphic calibration for the base of Zone 4 and the base of Subzone 4 alpha given by Pessagno *et al.* (1993). Before we do so, we have to check the reliability of our radiolarian ages, especially referring to the marker taxa of Pessagno *et al.* (1993).

The base of Zone 4 was originally (Pessagno *et al.* 1984) defined by the first occurrence of *Acanthocircus dicranacanthos* and *Vallupus hopsoni*. Since *A. dicranacanthos* is absent in Antarctica, due to the high paleolatitude, the first occurrence of the pantanelliid *Vallupus hopsoni* (Fig. 5I) is crucial in our discussion. The Austral character of the radiolarians requires caution in the interpretation of the first occurrence date of this species. Since the abundance (or probability of detection) of the pantanelliid subfamily Vallupinae is correlated with the overall abundance of Pantanelliidae, it is very unlikely to detect *Vallupus hopsoni* in standard residues (about 1 g in the Antarctic material), if pantanelliids make up less than 5% of a radiolarian sample. This fact may be partly responsible for the erroneous correlation of Pessagno *et al.* (1993). The abundance and diversity of pantanelliids was thought to decrease rapidly with latitude in the paleolatitudinal model of Pessagno & Blome (1986). Although pantanelliids sum up to 50.1% in one sample from Longing Gap, their abundance is strongly fluctuating in Antarctica. In Longing Gap (Fig. 3) the first occurrence of *Vallupus hopsoni* is noted in a sample (K 20-1) with 12.1% total pantanelliid abundance. The samples taken from just 2 and 3 m below (K 18, 19) contain a rich radiolarian fauna, but yield few pantanelliids. Only the samples K 14-1 and K 15 provide firm evidence for an age older than Subzone 4 beta. They contain diverse and abundant pantanelliids (15.6 and 13.8%, respectively) and even some vallupins, but no *Vallupus* was detected. Our last firm ammonite evidence for the Kimmeridgian is from between K 15 and K 18, but our first evidence of Tithonian stems from the level of K 18. Thus the first appearance of *Vallupus hopsoni* is only reliable within a 40 m thick interval separating K 15 and K 20-1. Although we do have ammonite evidence for early Tithonian below K 20-1 (*Hybonotum* zone), we cannot reject a late Kimmeridgian age for the base of Zone 4.

The last occurrence of *V. hopsoni* has been used as a corporeal marker within Subzone 4 alpha. At Longing Gap concretion level K 33/34 is the last horizon containing this species. This horizon is dated as middle/late Tithonian and is probably equivalent to the *Windhauseniceras internispinosum* zone of Argentina. Although we are not able to provide firm evidence for this zone in Antarctica (see discussion above), the presence of *V. hopsoni* in the *W. internispinosum* zone was established by Pujana (1991, 1996) in Argentina. In the Southern Alps, Subzone 4 alpha with *V. hopsoni* was recorded in the late middle to earliest late Tithonian *Chitinoidella* zone (cf. Kiessling 1995).

Perispyridium (Fig. 5J) is the only other primary marker taxon in Zone 4 that is present in Antarctica. Its last occurrence marks the top of Subzone 4 beta. The last occurrence of this genus provides a reliable datum, since *Perispyridium* is common throughout its stratigraphic range (with two exceptions) and suddenly disappears in the

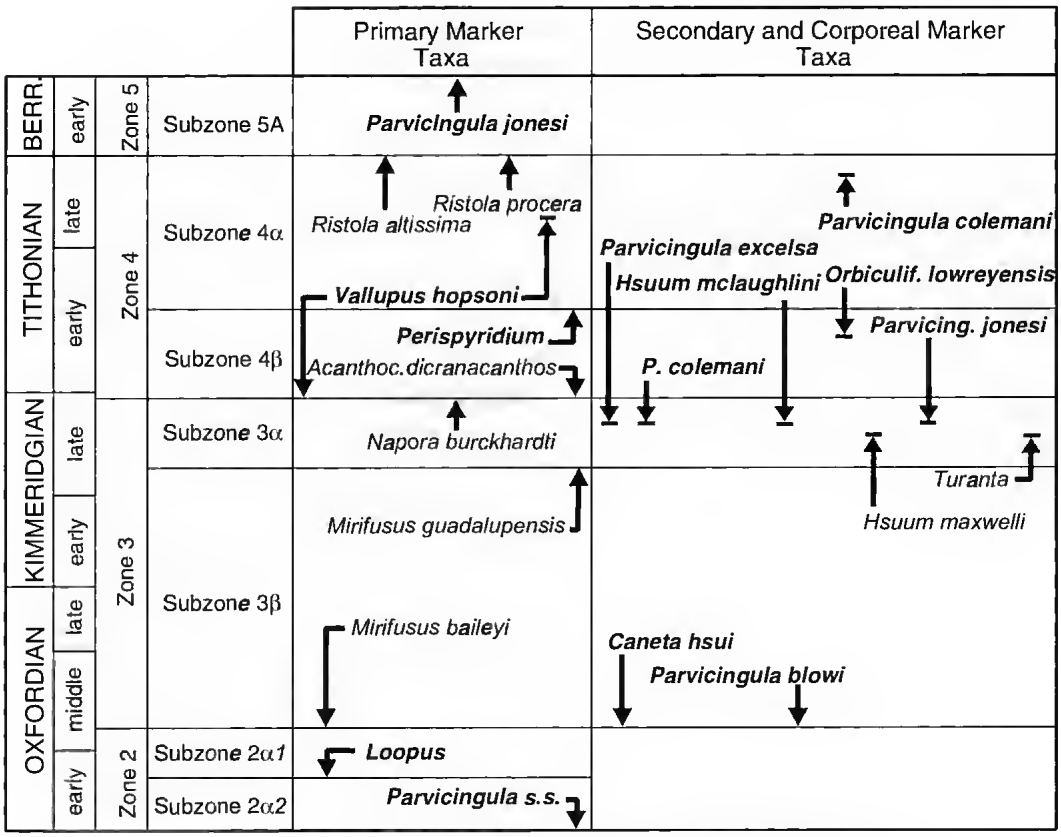

FIG. 9. — New chronostratigraphic assignment of the radiolarian biostratigraphy of Pessagno (1977b), Pessagno *et al.* (1984, 1987, 1993, 1994, 1996). Our data allow a modification of the Zone 3/Zone 4 boundary and the boundary between Subzone 4 alpha and 4 beta. The lower zones were modified following Baumgartner *et al.* (1995a, fig. 13). Marker taxa that are present in Antarctica are printed in bold. In this figure we use the Tithonian *sensu* Gallico as do Pessagno *et al.*; however it should be noted that subzone 4 beta ends before the middle Tithonian *sensu* Gerth.

sequence. However, there is a relatively thick interval with only sparse radiolarian faunas above the last record of *Perispyridium* in K 29. The first radiolarian sample with a sure absence of this genus is K 30b, which is only a few meters below the first record of the latest early Tithonian (*sensu* Gerth) *Mendozanus* zone. Hence, the top of Subzone 4 beta is assigned to the late early Tithonian (*sensu* Gerth = early early Tithonian *sensu* Gallico).

According to Pessagno *et al.* (1987), the last occurrence of *Parvicingula colemani* is noted in the upper part of Subzone 4 alpha (corporeal marker taxon). In Longing Gap, the last samples with *P. colemani* s.l. are above the level with first evidence of berriasellid ammonites indicating late Tithonian. Above the last occurrence of *P. colemani* no primary marker taxa (with the exception of *Parvicingula jonesi* Pessagno) of the North American zonation are present. However, Hull (1997) used the last occurrence of *Hsuum mclaughlini* as a secondary marker to define the top of Zone 4. This species is present near the top of the Longing Gap Section (K 65) which is assigned to the Berriasian. This would indicate that the top of Zone 4 should be assigned to the early Berriasian, consistent with new results of Pessagno *et al.* (1996). However, a relatively great faunal change is noted in Antarctica from K 60 onward, approximately consistent with the

Jurassic-Cretaceous boundary. Since no primary marker taxa are present, we tentatively correlate the Zone 4-Zone 5 boundary with the Jurassic-Cretaceous boundary and the first occurrence of *Williriedellum ruesti* (Tan Sin Hok) as figured in Kiessling & Scasso (1996, pl. 2/14).

Considering the statements above, we can revise the chronostratigraphic assignments of the North American radiolarian zonation (Table 2, Fig. 9). We are currently not able to affirm what led to the erroneous chronostratigraphic assignment of the zones and subzones discussed above. They may partly be due to the complex tectonic settings of both Mexico and California.

EVIDENCE FROM OTHER AREAS

The new chronostratigraphic assignment of the Zone 3-Zone 4 boundary is supported by new data from Germany.

Recent investigations in the Upper Jurassic of Southern Germany produced a very well-preserved and diverse radiolarian fauna in the Mörnsheim Formation (Zügel 1997) including *V. hopsoni*. The Mörnsheim Formation is correlated with the upper part of the *Hybonoticeras hybonotum* zone (Zeiss 1977) equivalent to an early early Tithonian age. In his ongoing work, Zügel (pers. comm. 1997) could recover *V. hopsoni* also in the chert-bearing limestones of Schamhaupten (Bavaria, Southern Germany). The locality is currently assigned to the uppermost Kimmeridgian (Bausch 1963).

In summary, the data from Germany do support an older age for the Zone 3-Zone 4 boundary. We can thus conclude that *V. hopsoni* first appears very close to the Kimmeridgian/Tithonian boundary. Other reports (Matsuoka 1992, Chiari *et al.* 1997) on the first occurrence of *V. hopsoni* do also support this interpretation, although they are not directly correlated with ammonite data.

ZONATION OF BAUMGARTNER *ET AL.* (1995B)

We have discussed above that the applicability of the Tethyan unitary association zonation (UAZ) is restricted owing to biogeographic differences. Additionally, there is a general trend from assemblages containing Tethyan taxa at the base to assemblages with a high degree of endemism at the top in the Ameghino Formation. However, a limited comparison is possible, if we sum up all our samples from the zones and subzones of the North American zonation. Three of the new unitary associations of Baumgartner *et al.* (1995a) were expected to occur in Antarctica:

– UAZ 11: late Kimmeridgian-early Tithonian;
– UAZ 12: early-early late Tithonian;
– UAZ 13: latest Tithonian-earliest Berriasian.

We will show below that UAZ 10 is unexpectedly also present at Longing Gap.

At Longing Gap, our samples from Zone 3, Subzone 3 alpha (K 2-K 15) contain the Tethyan taxa *Acaeniotyle umbilicata* gr. (Fig. 5L), *Acastea diaphorogona*, *Angulobracchia biordinalis*, *Archaeodictyomitra minoensis*, *Crucella theokaftensis* (Fig. 5F), *Gongylothorax favosus* (Fig. 5N), *Haliodictya* (?) *antiqua* s.l. (Fig. 5K), *Hsuum* sp. aff. *H. cuestaense*, *Napora pyramidalis*, *Perispyridium ordinarium* gr. (Fig. 5J), *Protunuma japonicus*, *Saitoum pagei*, *Sethocapsa trachyostraca* (Fig. 5M), *Triactoma mexicana*, and *Zhamoidellum ventricosum*. This assemblage was not observed in the Tethys and trying to apply the UAZ 95 leads to contradictory results. *Triactoma mexicana* (samples K 8-1, K 13) is predicted to range not higher than UAZ 9, but *Acaeniotyle umbilicata* (samples K 6, K 12, K 13, K 14-1) is not supposed to occur before UAZ 10. It is likely that the total range of *T. mexicana* is poorly defined in the UAZ considering the zonal assignment of *T. mexicana* to Subzone 4 beta by Pessagno *et al.* (1989) and its occurrence in UAZ 12 in the Southern Alps (cf. Kiessling 1995). *Gongylothorax favosus* is not reported above UAZ 10 according to Baumgartner *et al.* (1995a). This species was found only at the very base of the section (K 2, K 4) which may actually be assigned to UAZ 10. The samples above K 4 are assigned to UAZ 10-11. There are not sufficient Tethyan radiolarians to precisely define the UAZ of Baumgartner *et al.* (1995a). However, the application of the unpublished 127 UA range chart on the lumped zone 3 fauna results in a firm correlation with UAZ 10 (Guex, pers. comm. 1998). *Triactoma mexicana* ranges up to UAZ 11 in this recomputing.

Within Subzone 4 beta the following taxa used by Baumgartner *et al.* (1995a) are present in Antarctica; *Acanthocircus furiosus* (Fig. 5H), *Acastea diaphorogona*, *Angulobracchia biordinalis*, *Emiluvia chica*, *Emiluvia pessagnoi* s.l., *Gorgansium* sp., *Homocoparonaella elegans*, *Hsuum* aff. *cuestaense*, *Hsuum feliformis* (only detected in James Ross Island), *Loopus primitivus* (Fig. 5B), *Napora pyramidalis*, *Perispyridium ordinarium* gr., *Podobursa spinosa* s.l., *Podocapsa amphitreptera* s.l., *Suna echiodes* s.l. (Fig. 5O), *Triactoma tithonianum*, *Tritrabs rhododactylus* (Fig. 5G).

Again, there are some contradictions applying the unitary association zonation. *Gorgansium* ranges from UAZ 3-8 according to Baumgartner *et al.* (1995a), whereas *Hsuum feliformis* is thought to occur not earlier than UAZ 13. Leaving aside these problematic taxa would result in a correlation with UAZ 10 for the assemblage, as defined by *A. furiosus* (UAZ 10-20) and *H. elegans* (UAZ 4-10). However, *H. elegans* only occurs up to the middle part of Subzone 4 beta at Longing Gap. Above the last occurrence of *H. elegans* the assemblage would be assigned to UAZ 10-11. Again, the application of the 127 UA range chart helps to define the correlation more precisely. Guex (1998, pers. comm.) states that the lumped Subzone 4 beta fauna perfectly correlates with UAZ 11.

Only a few Tethyan taxa were found in the assemblages assigned to Subzone 4 alpha and Zone 5: *Gorgansium* sp., *Hsuum* aff. *cuestaense*, *Tethysetta boesii* gr. (Fig. 5C), *Triactoma tithonianum* are present indicating UAZ 10-13. A more exact correlation is not possible. Thus the presence of UAZ 12-13 cannot be proved in Antarctica.

The stratigraphic correlation of the North American zones with the UAZ can be controlled by new data from Europe (Kiessling 1995; Chiari *et al.* 1997; Zügel 1997). *V. hopsoni* was reported from UAZ 10 (Chiari *et al.* 1997) to UAZ 12-13 (Zügel 1997, cf. Kiessling 1995, 1996). Two samples from the Southern Alps bear *V. hopsoni* and lack *Perispyridium* and can thus be assigned to the base of Subzone 4 alpha. The sample from Ponte Setra near Fonzaso (see Kiessling 1996 for locality description) is from the transitional interval between the Ammonitico Rosso Superiore and the Maiolica which has been assigned to the late middle to earliest late Tithonian *Chitinoidella* zone by Grandesso (1977). This sample (PS 13) contains many species that make their first occurrence in UAZ 13: *Emiluvia chica decussata* Steiger, *Obesacapsula ruscoensis umbriensis* Jud, *Paronaella* (?) *tubulata* Steiger, *Pyramispongia barmsteinensis* (Steiger), and *Syringocapsa amphorella* (Jud). On the other hand, species like *Syringocapsa spinellifera* Baumgartner and *Williriedellum crystallinum* Dumitrica are also present. These have their last occurrence in UAZ 12 and UAZ 11, respectively. Therefore, PS 13 is preliminarily assigned to UAZ 12.

In summary the total range of *V. hopsoni* is from UAZ 10 to at least UAZ 12. The related form *Vallupus japonicus* has been shown by Matsuoka (1998) to range up to the early Berriasian (UAZ 13). UAZ 10 radiolatian assemblages can be observed from the base of the Longing Gap Section (Kimmeridgian) up to a horizon that has been dated as early Tithonian by ammonites. Baumgartner *et al.* (1995a) indicated a late Oxfordian-early Kimmeridgian age for UAZ 10. Although Baumgartner *et al.* (1995a: 1033) provide good evidence for this age, the age of the succeeding UAZ 11 is much less well defined. Considering the results above, we can conclude that UAZ 10 ranges up to at least the latest Kimmeridgian *Beckeri* zone. The new correlation of UAZ 10-13 with the North American zonation and their chronostratigraphic assignment ate indicated in Figure 10.

Zonation of Matsuoka (1995b)

The comparison with Matsuoka (1995b) is hampered by the rather coatse stratigraphic resolution of Matsuoka's Late Jurassic zonation. Only the *Pseudodictyomitra primitiva* zone can be traced in Antarctica, owing to the absence of other age-diagnostic taxa. This interval zone is defined by the last occurrence of *Hsuum maxwelli* at its base and the first occurrence of *Pseudodictyomitra carpatica* (Lozynyak) at its top. It is supposed to range from the early to the middle Tithonian.

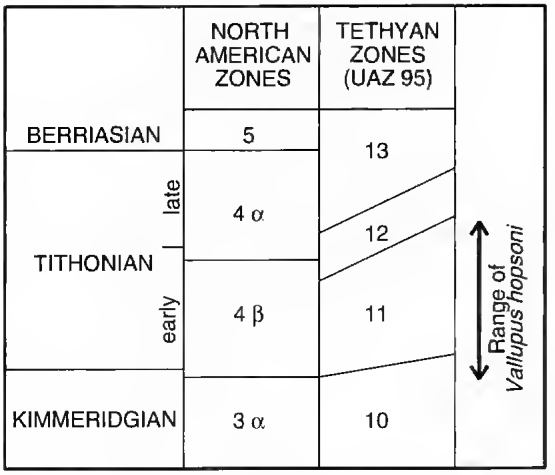

FIG. 10. — Correlation of the North American (Pessagno *et al.* 1993) and Tethyan (Baumgartner *et al.* 1995a) zonations for the Kimmeridgian/Tithonian interval.

According to Matsuoka (1995a, fig. 3), the *P. primitiva* zone ranges from the base of Zone 3 to the top of Subzone 4 beta. Considering our results and the correlation chart of Baumgartner *et al.* (1995a, fig. 13) this would imply a total range of the *P. primitiva* zone from the middle Oxfordian to early Tithonian. However, as the last occurrence of *Hsuum maxwelli* is noted within upper Subzone 3 alpha according to Pessagno *et al.* (1993), we suggest that the *Pseudodictyomitra primitiva* zone starts in the late Kimmeridgian. Since *Pseudodictyomitra carpatica* is absent due to biogeographical differences, the top of the *Pseudodictyomitra primitiva* zone cannot be defined.

Although the total range of *Loopus primitivus* (= *Pseudodictyomitra primitiva*) is uncertain according to Matsuoka (1995b) its major occurrence is definitely within the *Pseudodictyomitra primitiva* zone. At Longing Gap and Livingston Island, *L. primitivus* is found in Subzone 4 beta and at the very base of Subzone 4 alpha. Its first occurrence coincides with the first occurrence of *V. hopsoni* and its last occurrence is noted slightly above the last occurrence of *Perispyridium*. This agrees with a latest Kimmeridgian to probably middle Tithonian age and is consistent with Matsuoka's chronostratigraphic assignment for the *Pseudodictyomitra primitiva* zone.

CONCLUSIONS

New paleontological data from two Upper Jurassic localities on the Antarctic Peninsula allow the elaboration of a combined ammonite and radiolarian stratigraphy, provide a high stratigraphic resolution and allow to revise current chronostratigraphic calibrations of radiolarian zones.

The Ameghino Formation at Longing Gap ranges from the Kimmeridgian to the early Berriasian, whereas the Anchorage Formation at Byers Peninsula ranges from the Kimmeridgian/Tithonian to the latest Tithonian. Zone 3, Subzone 3 alpha, Zone 4, Subzones 4 beta and 4 alpha and probably the base of Zone 5 could be traced at Longing Gap, whereas on Byers Peninsula only Subzone 4 beta assemblages are well established.

The chronostratigraphic calibration of Zone 4 and its subzones as used in the North American radiolarian zonation (Pessagno *et al.* 1993) is revised herein. The base of Zone 4 is assigned to the Kimmeridgian/Tithonian boundary interval and the base of Subzone 4 alpha is located within the early Tithonian.

The North American radiolarian zones can be correlated with the unitary association zonation (Baumgartner *et al.* 1995a). Uppermost Zone 3, Subzone 3 alpha correlates with UAZ 10 and the base of Zone 4 agrees with UAZ 11 in Antarctica. Higher up in the sequences no correlation with the UAZ 95 is possible owing to increasing biogeographical differences. Evidence from the Southern Alps suggests that *Vallupus hopsoni* ranges up to at least UAZ 12.

The interval zonation used by Pessagno *et al.* (1993) has the advantages to be applicable to tropical as well as high latitude settings and to rely on only a few age diagnostic radiolarians. However, the absence of marker taxa has to be carefully proved, in order to overcome preservational, paleoceanographic and stochastic biases. With the chronostratigraphic corrections in this paper and those of Baumgartner *et al.* (1995a), we hope that the North American zonation can now be applied everywhere without contradictions. A major task for the future will be the definition of the Zone 4-Zone 5 boundary with the aid of high latitude radiolarians.

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Preliminary radiolarian biostratigraphy across the Jurassic-Cretaceous boundary from northwestern Turkey

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ABSTRACT

This is the first study from Turkey where radiolarians from calcareous sequences of the Sakarya Continent are tested in the delineation of the Jurassic-Cretaceous boundary. The Sakarya Continent, which comprises the southern part of northwest Turkey, was a Jurassic-Early Cretaceous carbonate platform micro-continent distant from terrestrial sediment influx. It was a site of pelagic carbonate deposition with abundant calcareous and siliceous microfossil input. Among 44 measured stratigraphic sections of the Jurassic-Lower Cretaceous deposits of the Sakarya Continent, four continuous sections (MK, KEL, AÇ, ÇD) which encompass the Tithonian-Berriasian boundary were selected for study. However, due to poor preservation and calcification of radiolarian faunas, only section KEL produced rich and well-preserved radiolarians. This section is 600 meters in thickness and spans the upper Tithonian-lower Berriasian interval. In addition to radiolarians, sec-

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calpionellids,
calcareous nannofossils.

tion KEL contains abundant calpionellids, calcareous nannofossils, benthic foraminifera and calcareous algae. The upper part of this stratigraphic section is made up of the Soğukçam Limestone which lithologically resembles the Biancone and Maiolica formations in the Umbria-Marche Region of Italy. The best preservation and richest radiolarian faunas were observed from the Soğukçam Limestone in section KEL. This is significant because many radiolarian studies as well as studies on magnetostratigraphy, calcareous nannofossils and calpionellid biostratigraphy in the Tethyan realm have been carried out on the Biancone and Maiolica formations. The rapid sedimentation rate, pelagic microfacies and well preserved non-calcified radiolarian faunas make section KEL ideal for the investigation of the Jurassic-Cretaceous boundary with radiolarians. The correlation between radiolarian faunas and co-occurring calpionellids and calcareous nannofossils in section KEL can be compared with similar biostratigraphic studies from the Biancone and Maiolica formations in Italy. The calcareous nannofossils in section KEL sometimes attain rock forming abundance, and the first appearance of nannoconids as well as their first abundance peak are recognized in this section. Throughout the present study, the boundary between Calpionellid standard zones A and B is considered as the Tithonian-Berriasian boundary. The close sampling interval, 15-20 meters, provides excellent resolution in documenting the first occurrences of numerous Cretaceous radiolarian species. These first occurrence datum points for radiolarian taxa are not concurrent. Due to the refined resolution of dating, a stepwise appearance of Cretaceous radiolarian faunas in section KEL is clearly observed; however, radiolarians do not delineate the Jurassic-Cretaceous boundary because a marked synchronous faunal turnover does not exist.

RÉSUMÉ

Étude biostratigraphique préliminaire des radiolaires à travers la limite jurassique-crétacé du nord-ouest de la Turquie.

Cette étude est la première de Turquie où les radiolaires ont été analysés pour décrire la limite jurassique-crétacé dans des séquences calcaires du continent de Sakarya localisé dans la partie sud de la Turquie nord-occidentale. Le continent de Sakarya a été une plate-forme isolée dans le Jurassique et Crétacé inférieur et un lieu de dépôt des carbonates pélagiques contenant des microfossiles calcaires et siliceux abondants. Parmi les 44 coupes stratigraphiques qui ont été mesurées dans les dépôts jurassiques et crétacés du continent de Sakarya, quatre coupes (MK, KEL, AÇ, ÇD) traversant la limite tithonique-berriasien ont été choisies pour cette étude. Néanmoins, à cause de la mauvaise préservation et de la calcification de la faune de radiolaires, seule la coupe KEL a produit des radiolaires bien préservés et abondants. L'épaisseur de cette coupe est de 600 mètres pour l'intervalle du Tithonien supérieur-Berriasien inférieur. En plus des radiolaires, la coupe KEL contient en abondance des calpionelles, des nannofossiles calcaires, des foraminifères benthiques et des algues calcaires. La partie supérieure de cette coupe est représentée par le Calcaire de Soğukçam qui ressemble par sa lithologie aux formations de Biancone et Maiolica dans la région d'Ombrie-Marche, en Italie. La faune de radiolaires la plus riche et la mieux préservée a été retrouvée dans le Calcaire de Soğukçam de la coupe KEL. Cette observation est importante parce que plusieurs études sur les radiolaires comme sur

la magnétostratigraphie et la biostratigraphie des nannofossiles calcaires et calpionelles, dans le domaine de la Téthys, ont été effectuées sur les formations de Biancone et Maiolica. Le taux de sédimentation élevé, le microfaciès pélagique et la faune de radiolaires non-calcifiée et bien préservée rendent la coupe de KEL idéale pour décrire la limite jurassique-crétacé avec les radiolaires. La corrélation entre la faune de radiolaires et la présence conjointe de calpionelles et de nannofossiles calcaires dans le même matériel en Turquie peut être comparée avec les études biostratigraphiques similaires des formations de Biancone et Maiolica. Les nannofossiles calcaires dans la coupe deviennent parfois le constituant majeur de la roche et la première apparition des nannoconides ainsi que leur première acme y ont été reconnues. La limite entre les zones standards des calpionelles A et B est considérée comme la limite du Tithonien et Bérriasien dans cette étude. L'échantillonnage serré de 15-20 mètres a fourni une résolution parfaite pour documenter la première apparition de plusieurs espèces de radiolaires. Ces premières apparitions ne sont pas simultanées. Grâce à la résolution fine des datations par échantillonnage serré, l'apparition graduelle de la faune des radiolaires crétacés a été nettement observée dans la coupe KEL ; néanmoins, les radiolaires ne décrivent pas la limite jurassique-crétacé puisqu'un changement synchronisé important n'existe pas dans la faune de radiolaires.

MOTS CLÉS
Radiolaires,
limite jurassique-crétacé,
Turquie du nord-ouest,
calpionelles,
nannofossiles calcaires.

INTRODUCTION

Radiolarians are diverse and abundant in Upper Jurassic-Lower Cretaceous sequences across the world. They have been studied intensively in the past thirty years from North America (Pessagno & Blome 1982, 1990; Pessagno *et al.* 1984; Yang & Pessagno 1989; Hull 1995, 1997), Europe and the Middle East (Baumgartner & Bernoulli 1976; Baumgartner 1980, 1984, 1987; Steiger 1992; Jud 1994; O'Dogherty 1994; Baumgartner *et al.* 1995a; Kiessling 1995, 1996; Dumitrica *et al.* 1997), Japan (Nakaseko & Nishimura 1981; Aita & Okada 1986; Matsuoka & Yao 1986; Aita 1987; Matsuoka 1995a, b, c; Yang & Matsuoka 1997) and southern high latitudes (Baumgartner 1992, 1993; Kiessling & Scasso 1996).

The main purpose of this study is to compare radiolarian biostratigraphy with biozonations of calpionellids, calcareous nannofossils and other calcareous microfossils (e.g. algae and benthic foraminifera) across the Jurassic-Cretaceous boundary on samples from northwest Turkey, near Ankara. Our objectives are: (1) reporting the radiolarian assemblage from this boundary for the first time from Turkey; (2) investigating the chronostratigraphic ranges of our radiolarian faunas; (3) correlating our radiolarian biostratigraphy with that of co-occurring calcareous microfossils.

The study area is located in the southern part of northwest Turkey near the towns of Kozluca, Kabalar and Aktaş (Fig. 1) which lie northwest of Turkey's capital, Ankara. Altiner *et al.* (1991) studied the stratigraphy and paleogeographic evolution of this region where the Upper Jurassic-Lower Cretaceous successions occupy approximately 120.000 square kilometers. Altiner *et al.* (1991) measured 44 stratigraphic sections from these successions in which four sections were reported to contain radiolarians. These four sections are AÇ (by Aktaş), KEL (by Kozluca), MK (by Kabalar) and ÇD (by The Ismet Paşa railway station) (Fig. 1). Among these four sections, only section KEL produced well

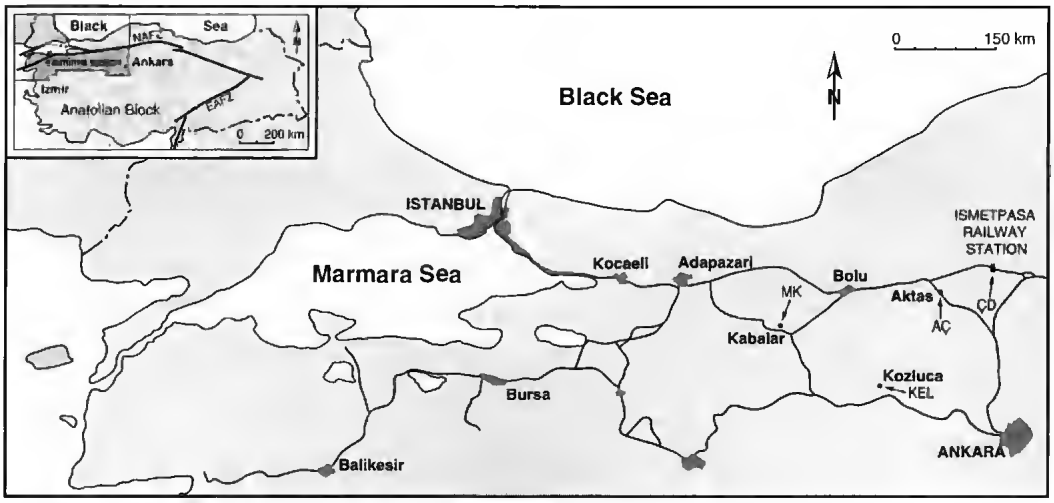

FIG. 1. — Geographic map of study area (modified after Altiner *et al.* 1991) illustrating locations of radiolarian bearing stratigraphic sections (AÇ, ÇD, KEL, MEK).

preserved radiolarians. It is also the thickest of these four sections (600 m for the upper Tithonian and Berriasian interval) and provides superior resolution for marking the Jurassic-Cretaceous boundary due to its high to very high sedimentation rate.

Within a tectono-stratigraphic framework, the southern part of northwestern Turkey contains the deposits of a Mesozoic micro-continent, the Sakarya Continent (Fig. 2). The Sakarya Continent was a Jurassic-Cretaceous carbonate platform micro-continent amidst the branches of the Neo-Tethys (Şengör & Yilmaz 1981). During the Tithonian-Berriasian interval, the Sakarya Continent was distant from terrestrial sediment influx and hence a site of carbonate deposition. This micro-continent rifted away from Gondwanaland in the Jurassic and moved northward to eventually collide with Eurasia (Rhodope-Pontide Fragment in Fig. 2) by the end of the Late Cretaceous (Şengör & Yilmaz 1981). Today, the Sakarya Continent is a part of Turkey and bound to the Rhodope-Pontide Fragment in the north by the Intra-Pontide Suture and to the Tauride and Kirşehir Blocks in the south by the Izmir-Ankara Suture (Fig. 2). These sutures are ophiolite belts remaining from the closure of the branches of Neo-Tethys.

LITHOLOGY

Section KEL (600 meters in thickness) contains the Tithonian-Berriasian pelagic limestone deposits of the Sakarya Continent. The thickness of the section, its pelagic microfacies and rich microfossil content of radiolarians, calpionellids, calcareous nannofossils, benthic foraminifera and calcareous algae, make it ideal for the examination of the Jurassic-Cretaceous boundary. Calcareous nannofossils in this section occasionally attain rock-forming abundance. Located at Kozluca, northwest of Beypazari, section KEL consists of the Yosunlukbayiri Formation in its lower portion (samples 24-36) and the Soğukçam Limestone in its upper part (samples 2-23) (Altiner *et al.* 1991) (Fig. 3).

The Yosunlukbayiri Formation is a thick calciturbiditic sequence. The upper part of this formation, outcropping in section KEL, is composed of fine detritic limestones containing six distinct olistostrome levels. The uppermost detritic limestone beds contain *Zoophycus* as well as abundant calpionellids and calcareous nannofossils (Altiner *et al.* 1991; Özkan 1993a, b).

The Yosunlukbayiri Formation is gradually overlain by the porcelaneous micrites of the Soğukçam Limestone in the area. The lower part of the

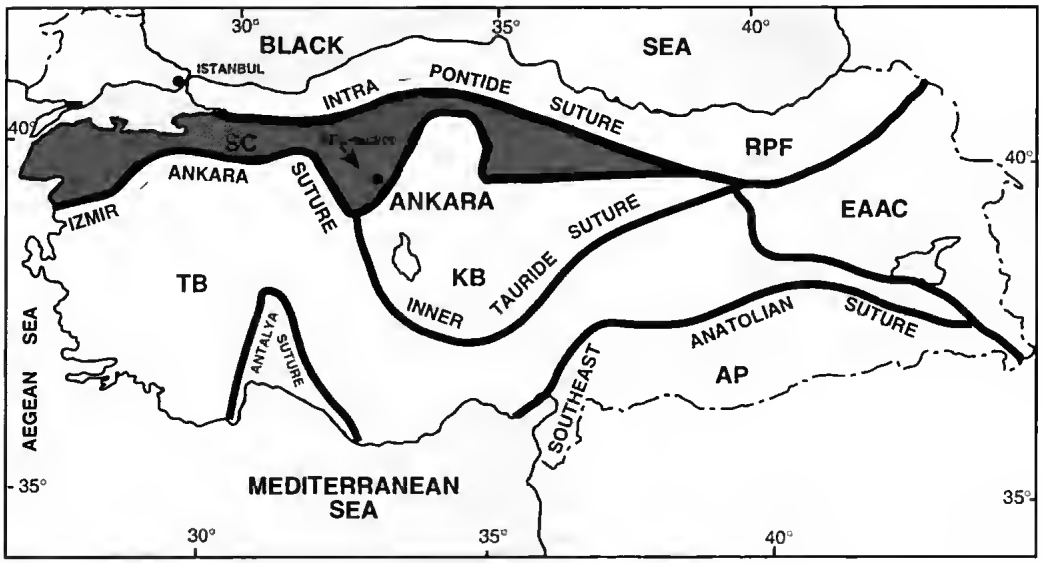

FIG. 2. — Map of Turkey illustrating tectono-stratigraphic units (modified after Şengör 1984). **SC**, Sakarya Continent; **RPF**, Rhodope-Pontide Fragment; **TB**, Tauride Block; **KB**, Kirşehir Block; **EAAC**, East Anatolian Accretionary Complex; **AP**, Arabian Plate.

Soğukçam Limestone (KEL 2-24) is characterized by thin, medium or thickly bedded, sometimes silicified, white to cream micritic limestones bearing chert nodules and intercalated with fine turbidite layers (Altiner *et al.* 1991). The Soğukçam Limestone lithologically resembles the Biancone and Maiolica formations in the Umbria-Marche Region in Italy (Farinacci *et al.* 1981a, b; Altiner *et al.* 1991). The Biancone and Maiolica formations have been extensively studied for calpionellids, calcareous nannofossils and magnetostratigraphy (e.g. Lowrie & Channell 1983; Erba & Quadria 1987; Channell *et al.* 1987, 1993) as well as for radiolarians (e.g. Baumgartner 1984; Jud 1994; O'Dogherty 1994). The strong lithologic similarity between the Soğukçam Limestone and the Maiolica and Biancone formations is due to their deposition in the same ocean, during the same time interval, and under similar conditions as submerged carbonate platfotms distant from terrestrial sediment influx (see Altiner *et al.* 1991). For this reason the radiolarian biostratigraphy we present here and its correlation to calpionellid and calcareous nannofossil biozonations previously established for the same section (KEL) is significant as a correlative example from Turkey to the previous studies in Italy.

THE JURASSIC-CRETACEOUS BOUNDARY

The Jurassic-Cretaceous boundary is one of the most problematic system boundaries because the Tithonian does not have a stratotype, the lower parts of the Berriasian tend to lack fossils in many parts of Western Europe, and the boundary does not correspond to any major faunal or floral turnover (Hoedemaeker 1987; Oloriz & Tavera 1989; Remane 1991; Pessagno *et al.* 1997). Ammonites (Kemper *et al.* 1981; Hoedemaeker 1991), *Buchia* (Zakhanov 1987; Pessagno *et al.* 1987a, b; Hoedemaeker 1991; Pessagno *et al.* 1993), calpionellids (Le Hegarat & Remane 1968; Allemann *et al.* 1971; Remane 1964, 1985, 1986; Remane *et al.* 1986; Cecca *et al.* 1989) and calcareous nannofossils (Thierstein 1975; Cooper 1985; Bralower 1990; Bown & Özkan 1992; Özkan 1993a, b) have been utilized in biostratigraphically marking this boundary. Ammonites, which are traditionally considered the basis of standard and high resolution biostratigraphy, become strongly provincialized during the Tithonian-Berriasian interval. This provincialism creates problems in correlation between the Tethyan and Boreal realms

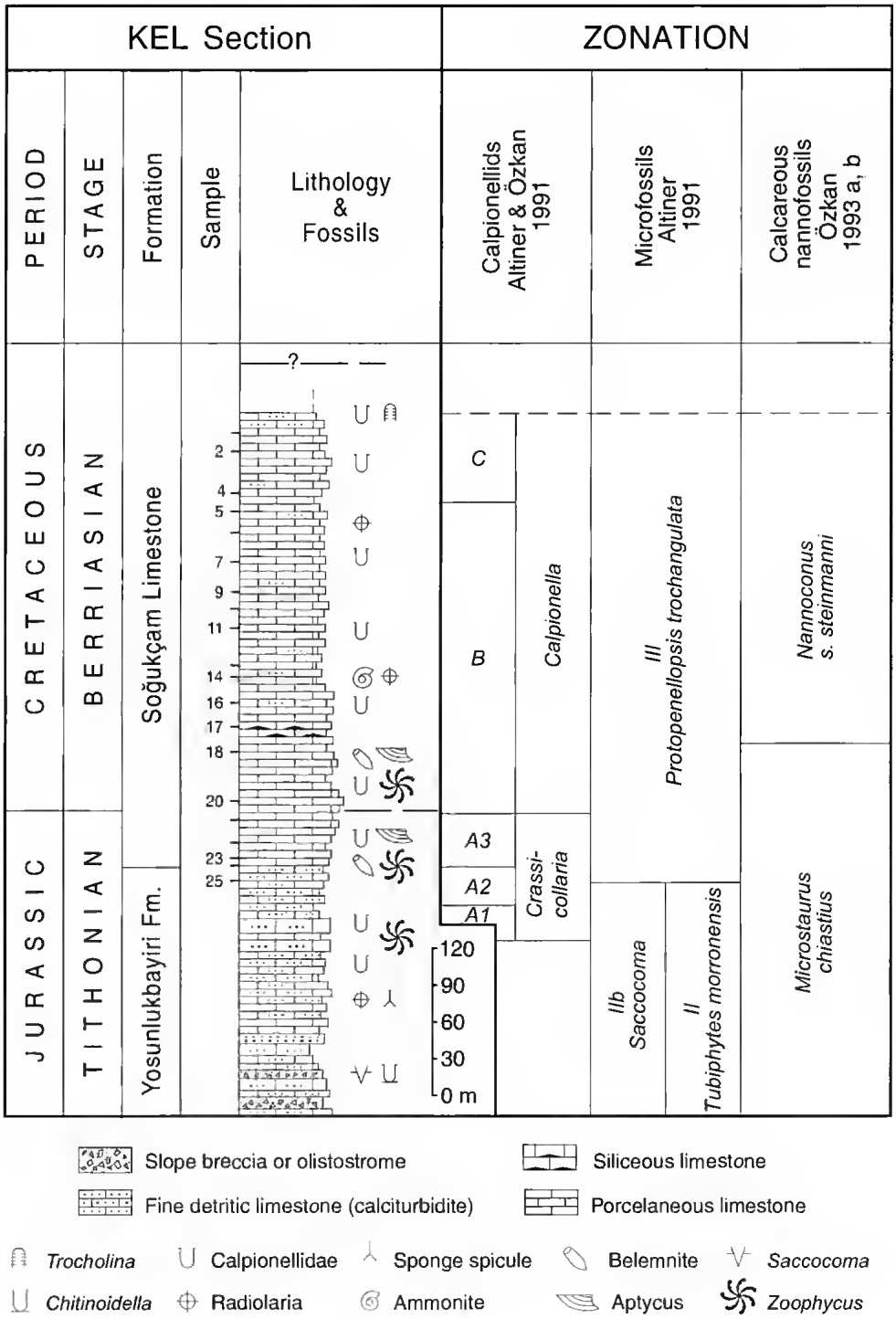

FIG. 3. — Calpionellid, calcareous nannofossil, and benthic foraminifera and algae biozonations on stratigraphic section KEL. Rich radiolarian assemblages were recovered from the numbered samples in the figure.

(Jeletsky 1984; Zeiss 1984, 1986; Remane 1991; Pessagno *et al.* 1997). According to Pessagno *et al.* (1997) calpionellids are diachronous with longer ranging zones in North America than in Europe. However, since Turkey is located in Eurasia, and since calpionellid biozones are well established in Europe (Allemann *et al.* 1971; Trejo 1980; Remane *et al.* 1986; Altiner & Özkan 1991; Pop 1994a,b; 1996; Grün & Blau 1997), calpionellid zones are used to mark the boundary in this study.

Le Hegarat & Remane (1968) placed the Jurassic-Cretaceous boundary within Calpionellid standard zone B in the stratotype of the Berriasian. For this reason, Altiner & Özkan (1991) also placed the boundary in zone B in section KEL. However, since the boundary between Calpionellid standard zones A and B also corresponds to the boundary between the *Durangites* and *Euxinus* ammonite zones, the Jurassic-Cretaceous boundary was accepted as the limit between Calpionellid standard zones A and B at the Colloque (Anonymous 1975), and by Cecca *et al.* (1989). Other researchers (Jeletsky 1984; Channell & Grandesso 1987; Özkan 1993b; Grün & Blau 1997) consider the limit between Calpionellid standard zones A and B as the Jurassic-Cretaceous boundary as well. On the other hand, Tavera *et al.* (1994) stated that the boundary between *Durangites* and *Jacobi* ammonite zones does not correspond to the limit between Calpionellid standard zones A and B in the Vocontian Region (see also Oloriz & Tavera 1989) but rather to a level within Calpionellid standard zone A. We also consider the Jurassic-Cretaceous boundary to correspond to the limit between Calpionellid standard zones A and B in section KEL based on the consensus reached at the Colloque (1975) and many subsequent publications accepting this limit as the Jurassic-Cretaceous boundary. Therefore, the limit between Calpionellid standard zones A and B in section KEL falls between samples 20 and 21 (Fig. 3).

The development of a magnetic polarity time scale for the Jurassic-Cretaceous boundary (Ogg & Lowrie 1986; Ogg *et al.* 1991) and the correlation of this time scale with biozonations of calcareous nannofossils (Bralower *et al.* 1989), calpionellids (Channel & Grandesso 1987) and radiolarians (Jud 1994) are important advances in the multidisciplinary delineation of this boundary. According to Ogg (1992) the boundary is defined as the base of the reverse polarity chron M 18R and Bralower *et al.* (1989) correlate the base of M 18R with the boundary between Calpionellid standard zones A and B.

The following is a brief discussion on comparison of radiolarian biozonations across the Jurassic-Cretaceous boundary from North America (Pessagno 1977a; Pessagno *et al.* 1987a; Pessagno & Blome 1990; Pessagno *et al.* 1993; Hull 1997), Europe (Baumgartner 1980, 1984, 1987; Steiger 1992; Jud 1994; Baumgartner *et al.* 1995b; Dumitrica *et al.* 1997) and Japan (Matsuoka & Yao 1986; Aita 1987; Matsuoka 1995a, b, d; Yang & Matsuoka 1997) which illustrates problems of provincialism and diachroneity among radiolarians:

North America. Originally the top of zone 4 was defined as the Jurassic-Cretaceous boundary (Pessagno 1977a; Pessagno *et al.* 1984, 1987b, 1993; Pessagno & Mizutani 1992). Recently the uppermost part of subzone 4a has been revised and is considered to belong to the Lower Cretaceous (Berriasian). This boundary within subzone 4a coincides with the tops of the *Durangites* (ammonite) and the *Buchia piochii* zones (bivalve) (Pessagno *et al.* 1997). It should be noted here that originally Pessagno (1977a) and subsequently Pessagno *et al.* (1984, 1987b, 1993) considered the last occurrences of *Ristola altissima* and *Ristola procera* (primary marker taxa) for defining the top of zone 4 (and subzone 4a). *Parvicingula colemani* becomes extinct slightly below this level. The datum where *Parvicingula colemani* becomes extinct falls within the *Pseudodictyomitra carpatica* zone of Japan (Yang & Matsuoka 1997).

Europe. Baumgartner *et al.* (1995b) utilize unitary associations among radiolarian taxa to construct radiolarian biozones (UAZ 95). Each biozone is defined by a group of radiolarian taxa that only co-occur in that zone. When UAZ 95 is compared with North American zones (Pessagno *et al.* 1993), diachronism between the zones is evident. Discrepancies between first appearance data of some taxa between Europe

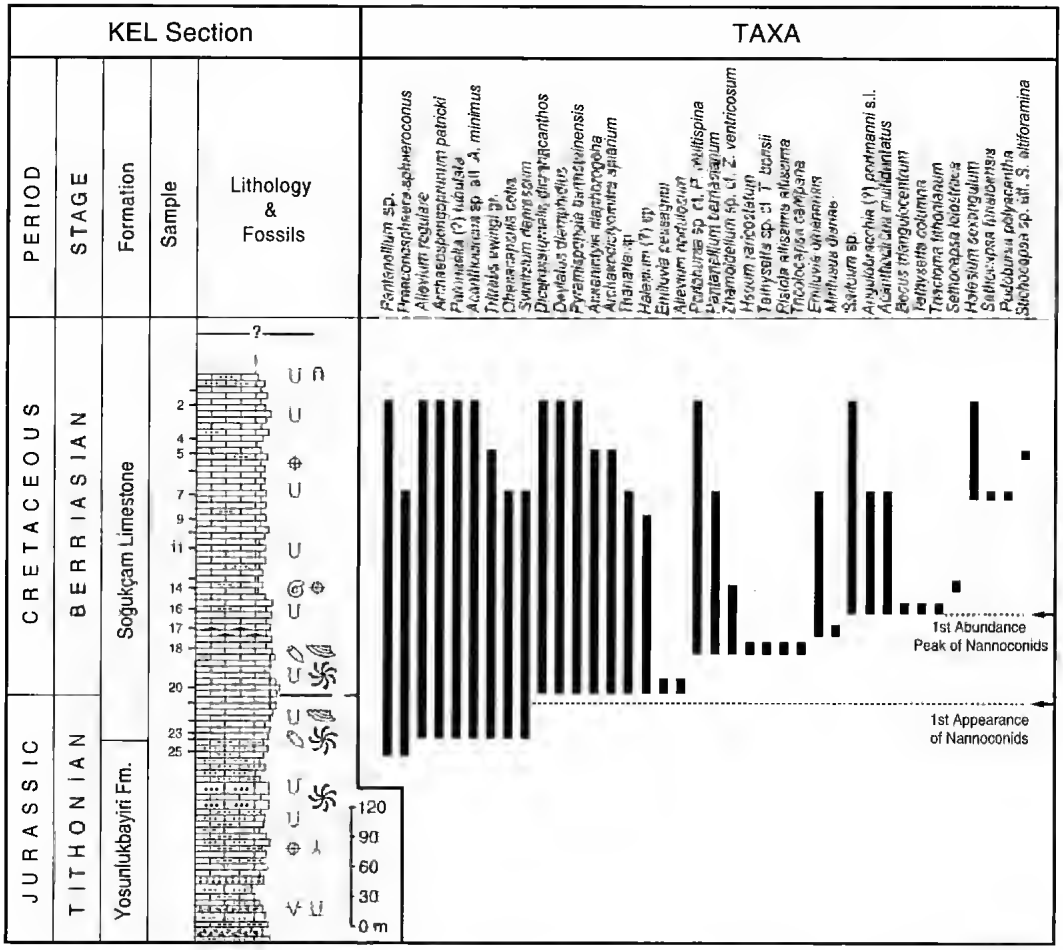

Fig. 4. — Chronostratigraphic distribution of radiolarian fauna in section KEL. Symbols on stratigraphic section are the same as in Fig. 3.

and North America as well as radiolarian provincialism during the Late Jurassic-Early Cretaceous interval hamper the correlation of radiolarian biozones between North America and Europe; however, in some recent studies this correlation is becoming increasingly closer (Hull 1997).

Japan. The evolutionary first appearance of *Pseudodictyomitra carpatica* from *Loopus primitivus* (= *Pseudodictyomitra primitivus*) defines the boundary between the *Loopus primitivus* and *Pseudodictyomitra carpatica* zones. This boundary is in the latest Tithonian and it is approximately one million year older than the Jurassic-Cretaceous boundary in both Japanese Island sections and in the western Pacific deep ocean basin (Matsuoka 1995a, b; Yang & Matsuoka 1997).

RESULTS AND DISCUSSION

Section KEL was previously studied for its calpionellids (Altiner & Özkan 1991), calcareous nannofossils (Özkan 1993a, b) and benthic foraminifera and calcareous algae (Altiner 1991). In the present study, we compare these previously established zonations for the same section with our radiolarian biostratigraphy. Section KEL was reported to contain abundant radiolarians in 28 of 40 samples from thin section examinations

(Özkan 1993a). However, well-preserved and rich radiolarian faunas could only be obtained from the upper part of the section that corresponds to the Soğukçam Limestone in section KEL. In the lower part of the section radiolarian preservation is poor and hence recovery is very low. Radiolarians are recovered from samples in section KEL assigned to Calpionellid standard zones A2 (KEL 25-26), A3 (KEL 20-24), B (KEL 19-5) and C (above KEL 4) (Altiner & Özkan 1991) (Fig. 3). Altiner & Özkan (1991) also report the presence of *Duvalia tithonica* (belemnite) in subzone A2 whose range is known to be from late Tithonian to early Berriasian (*Euxinus* zone). We will first discuss calcareous microfossil biostratigraphy for section KEL.

Biostratigraphy of co-occurring calcareous microfossils

The Jurassic-Cretaceous boundary is considered as the boundary between Calpionellid standard zones A and B which corresponds to the location between samples 20 and 21 in section KEL (Fig. 3). This boundary falls within the upper part of the *Microstaurus chiastius* calcareous nannofossil zone in section KEL and it is impossible to delineate with Altiner's (1991) foraminiferal and algal zonation where his *Protopeneroplis trochangulata* zone (zone III) transgresses the boundary (Fig. 3).

Radiolarian biostratigraphy

Due to the poor preservation of radiolarians in the fine detritic limestones of the Yosunlukbayiri Formation, the initial occurrences of the majority of Cretaceous radiolarians in section KEL begin near the base of the Soğukçam Limestone. In section KEL, the first appearance of nannoconids as a group is observed in sample KEL 21 (Fig. 4) from which well-preserved radiolarians could not be extracted. The Jurassic-Cretaceous boundary corresponds to the first occurrences of *Dicerosaturnalis dicranacanthos*, *Deviatus diamphidius*, *Pyramispongia barmsteinensis*, *Acaeniotyle diaphorogona*, *Archaeodictyomitra apiarium*, *Thanarla* sp., *Halesium* (?) sp., *Emiluvia pessagnoi* and *Alievium nodulosum* in this section. Also, the first occurrences of *Saitoum* sp., *Angulobracchia portmanni* s.l., *Acanthocircus multidentatus*, *Becus triangulocentrum*, *Triactoma tithonianum* and *Tethysetta columna* correspond to the first peak in nannoconid abundance as defined by Özkan (1993a, b) (Fig. 4) in section KEL. As a general pattern, the initial occurrences of Cretaceous radiolarians throughout the section are not abrupt, but stepwise, emphasizing that a major radiolarian faunal turnover does not exist across the Jurassic-Cretaceous boundary in northwest Turkey.

The chronostratigraphic distribution of radiolarian taxa within section KEL (Fig. 3) does not comply with any of the established radiolarian zonations in North America or Japan. This is due to the lack of biostratigraphically index species such as *Pseudodictyomitra carpatica*, *Ristola procera* or *Parvicingula colemani* in out samples. The taxa we describe herein (e.g. *Alievium regulare*, *Dicerosaturnalis dicranacanthos*, *Mirifusus dianae*, *Tethysetta boesii*, *Deviatus diamphidius*, *Pantanellium berriasianum*, *Hsuum raricostatum*) enables us to correlate section KEL with Jud's (1994) biozone D2 and UAZ 95 zones 13 and 14 (Baumgartner *et al.* 1995a).

SYSTEMATIC MICROPALEONTOLOGY

The supra-generic classification for radiolarians is based on, for the most part, Dumitrica's (1995) classification. The synonymy lists contain only a few representative studies.

Subclass RADIOLARIA Muller, 1858
Order POLYCYSTINA Ehrenberg, 1838
emend. Riedel, 1967
Suborder NASSELLARIA Ehrenberg, 1875
Family ARCHAEODICTYOMITRIDAE
Pessagno, 1976
Genus *Archaeodictyomitra* Pessagno, 1976

Archaeodictyomitra apiarium (Rüst, 1885)
(Fig. 5B)

Lithocampe apiarium Rüst, 1885 (*fide* Jud, 1994): 314, pl. 39 (14), fig. 8.

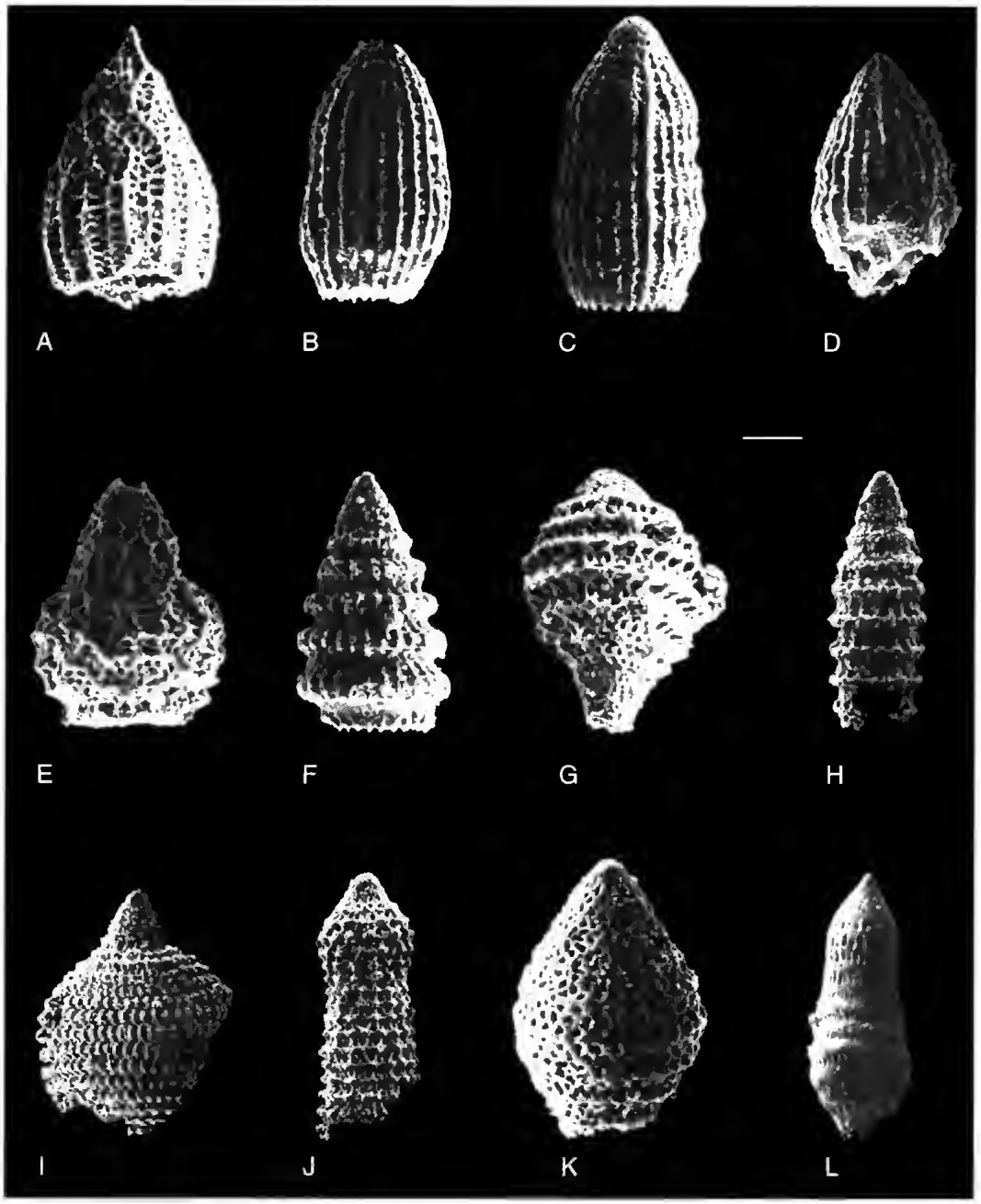

FIG. 5. — **A**, *Hsuum rancostatum* Jud (KEL 18); **B**, *Archaeodictyomitra apiarium* Kocher (KEL 7); **C**, *Archaeodictyomitra* sp. cf. *A. minoensis* (Mizutani) (KEL 7); **D**, *Thanarla* sp. (KEL 16); **E**, *Stichocapsa* sp. aff. *S. altiforamina* Tumanda (KEL 4); **F**, *Svinitzium depressum* (Baumgartner) (KEL 20); **G**, *Tethysetta* sp. cf. *T. boesii* (Parona) (KEL 18); **H**, *Tethysetta columna* (Rüst) (KEL 16); **I**, *Mirifusus dianae* (Karrer) (KEL 17); **J**, *Ristola altissima altissima* (Rüst) (KEL 18); **K**, *Tethysetta ovoidata* Dumitrica (KEL 11); **L**, *Loopus yangi* Dumitrica (KEL 25). Scale bar: A, 55 µm; B, E, K, 45 µm; C, H, 65 µm; D, G, 40 µm; F, 50 µm; I, 120 µm; J, 75 µm; L, 70 µm.

Archaeodictyomitra apiara – Pessagno 1977a: 41, pl. 6, figs 6, 14. – Baumgartner 1984: 758, pl. 2 figs 5-6.
Archaeodictyomitra apiarium – Kocher 1981 (*fide* Jud, 1994): 56, pl. 12, fig. 13. – Jud 1994: 62, pl. 3, figs 10, 11. – Baumgartner *et al.* 1995a: 98, pl. 3263, figs 1-7(H). – Dumitrica *et al.*, 1997: 38, pl. 7, fig. 7.

OCCURRENCE. — Samples KEL 5-20; from Jurassic-Cretaceous boundary to boundary between Calpionellid standard zones B and C.

Archaeodictyomitra sp.
cf. ***A. minoensis*** (Mizutani, 1981)
(Fig. 5C)

OCCURRENCE. — Samples KEL 5-7; from upper portion of Calpionellid standard zone B to boundary between zones B and C.

Genus *Thanarla* Pessagno, 1977b

Thanarla sp.
(Fig. 5D)

OCCURRENCE. — Samples KEL 7-20; from Jurassic-Cretaceous boundary to upper part of Calpionellid standard zone B.

Family HSUUIDAE Pessagno & Whalen, 1982
Genus *Hsuum* Pessagno, 1977a
emend. Takemura, 1986

Hsuum raricostatum Jud, 1994
(Fig. 5A)

Hsuum raricostatum Jud, 1994: 81, pl. 12, figs 3-5. – Baumgartner *et al.* 1995a: 286, pl. 3591, figs 1-3. – Dumitrica *et al.* 1997: 46, pl. 10, fig. 1.

OCCURRENCE. — Sample KEL 18; in Calpionellid standard zone B.

Family PARVICINGULIDAE Pessagno, 1977a
Genus *Mirifusus* Pessagno, 1977a

Mirifusus dianae (Karrer, 1867)
(Fig. 5I)

Lagena dianae Karrer, 1867 (*fide* Jud, 1994): 365, pl. 5, figs 8a, b.
Mirifusus dianae – Dumitrica & De Wever 1991: 553-557, figs 1, 2a, b. – Dumitrica *et al.* 1997: 52, pl. 11, fig. 8.
Mirifusus dianae minor – Baumgartner 1984: 772, pl. 5, figs 11, 14. – Jud 1994: 84, pl. 13, fig. 2. – Baumgartner *et al.* 1995a: 314, pl. 3286, figs 1-5.

OCCURRENCE. — Sample KEL 17; in Calpionellid standard zone B.

Genus *Ristola* Pessagno & Whalen, 1982
emend. Baumgartner, 1984

Ristola altissima altissima
(Rüst, 1885)
(Fig. 5J)

Lithocampe altissima Rüst, 1885 (*fide* Pessagno, 1977a): 315 (45), pl. 40, fig. 2.
Parvicingula altissima – *emend.* Pessagno 1977a: 85, pl. 8, figs 9-10.
Ristola altissima (Rüst) – Baumgartner 1984: 783, pl. 8, fig. 3, *non* figs 4, 9. – Dumitrica *et al.* 1997: 52, pl. 11, fig. 5, ?7.
Ristola altissima altissima – Jud 1994: 101, pl. 19, fig. 1. – Baumgartner *et al.* 1995a: 472, pl. 3241, figs 1-5(H).

OCCURRENCE. — Sample KEL 18; in Calpionellid standard zone B.

Genus *Svinitzium* Dumitrica, 1997

Svinitzium depressum
(Baumgartner, 1984)
(Fig. 5F)

Pseudodictyomitra depressum Baumgartner, 1984: 782, pl. 8, figs 2, 7, 8, 11.
Wrangellium depressum – Baumgartner *et al.* 1995a: 632, pl. 3284, figs 1-5.
Svinitzium depressum – Dumitrica *et al.* 1997: 53, pl. 11, figs 11, 17.

OCCURRENCE. — Samples KEL 7-23; from Calpionellid standard zone A subzone 3 to zone B.

Genus *Tethysetta* Dumitrica, 1997

Tethysetta sp. cf. ***T. boesii***
(Parona, 1890)
(Fig. 5G)

OCCURRENCE. — Sample KEL 18; in Calpionellid standard zone B.

REMARKS
The broken nature of the specimen makes a positive assignment of the present species to *T. boesii* difficult.

Tethysetta columna (Rüst, 1898)
(Fig. 5H)

Lithocampe columna Rüst, 1898: 63, pl. 18, fig. 5.
Parvicingula columna – Jud 1994: 116, pl. 23, fig. 17.
Tethysetta columna – Dumitrica *et al.* 1997: 49, pl. 11, figs 13-15.

OCCURRENCE. — Sample KEL 16, in Calpionellid standard zone B.

REMARKS
This species differs from *Wrangellium columnarium* Jud, 1994 by having three rows of pores per chamber.

Tethysetta ovoidala Dumitrica, 1997
(Fig. 5K)

Tethysetta ovoidala – Dumitrica *et al.* 1997: 50, pl. 50, figs 21, 22.

OCCURRENCE. — Sample KEL 11; in Calpionellid standard zone B.

Family PSEUDODICTYOMITRIDAE
Pessagno, 1977b
Genus *Loopus* Yang, 1993

Loopus yangi Dumitrica, 1997
(Fig. 5L)

Loopus yangi – Dumitrica *et al.* 1997: 31, pl. 5, figs 8, 9.

OCCURRENCE. — Sample KEL 25, Calpionellid standard zone A subzone 2.

Family THEOPERIDAE Haeckel, 1881
emend. Riedel, 1967 *emend.* Takemura, 1986
Genus *Stichocapsa* Haeckel, 1881

Stichocapsa sp. cf. ***S. altiforamina***
Tumanda, 1989
(Fig. 5E)

OCCURRENCE. — Sample KEL 4; just below the boundary between calpionellid zones B and C.

Family SETHOCAPSIDAE Haeckel, 1881
Genus *Gongylothorax* Foreman, 1968
emend. Dumitrica, 1970

Gongylothorax sp.
(Fig. 6E)

OCCURRENCE. — Sample KEL 25; in Calpionellid standard zone A subzone 2.

Genus *Sethocapsa* Haeckel, 1881

Sethocapsa funatoensis Aita, 1987
(Fig. 6A)

Sethocapsa funatoensis Aita, 1987: 73, pl. 2, figs 6a-7b; pl. 9, figs 14-15. – Baumgartner *et al.* 1995: 494, pl. 3070, figs 1-5(H).
Zhamoidellum funatoensis – Hull 1997: 132, pl. 38, figs 13, 15.

OCCURRENCE. — Sample KEL 7; in the upper part of Calpionellid standard zone B

Sethocapsa leiostraca Foreman, 1973
(Fig. 6D)

Sethocapsa leiostraca Foreman, 1973: 268, pl. 12, figs 5-6. – Jud 1994: 105, pl. 20, fig. 5. – Baumgartner *et al.* 1995a: 498, pl. 3062, figs 1-5(H).

OCCURRENCE. — Sample KEL 14; in Calpionellid standard zone B

Family SPONGOCAPSULIDAE
Pessagno, 1977a
Genus *Obesacapsula* Pessagno, 1977a

Obesacapsula cetia (Foreman, 1973)
(Fig. 6B)

Sethocapsa cetia Foreman, 1973: 267, pl. 12, fig. 1; pl. 16, fig. 19.
Obesacapsula cetia – Baumgartner 1992 : 325, pl. 12, fig. 1. – Jud 1994: 87, pl. 13, fig. 11. – Baumgartner *et al.* 1995a: 342, pl. 3203, figs 1-4(H).

OCCURRENCE. — Samples KEL 7-23; from Calpionellid standard zone A subzone 3 to upper part of zone B.

Family WILLIRIEDELLIDAE Dumitrica, 1970
Genus *Cryptamphorella* Dumitrica, 1970

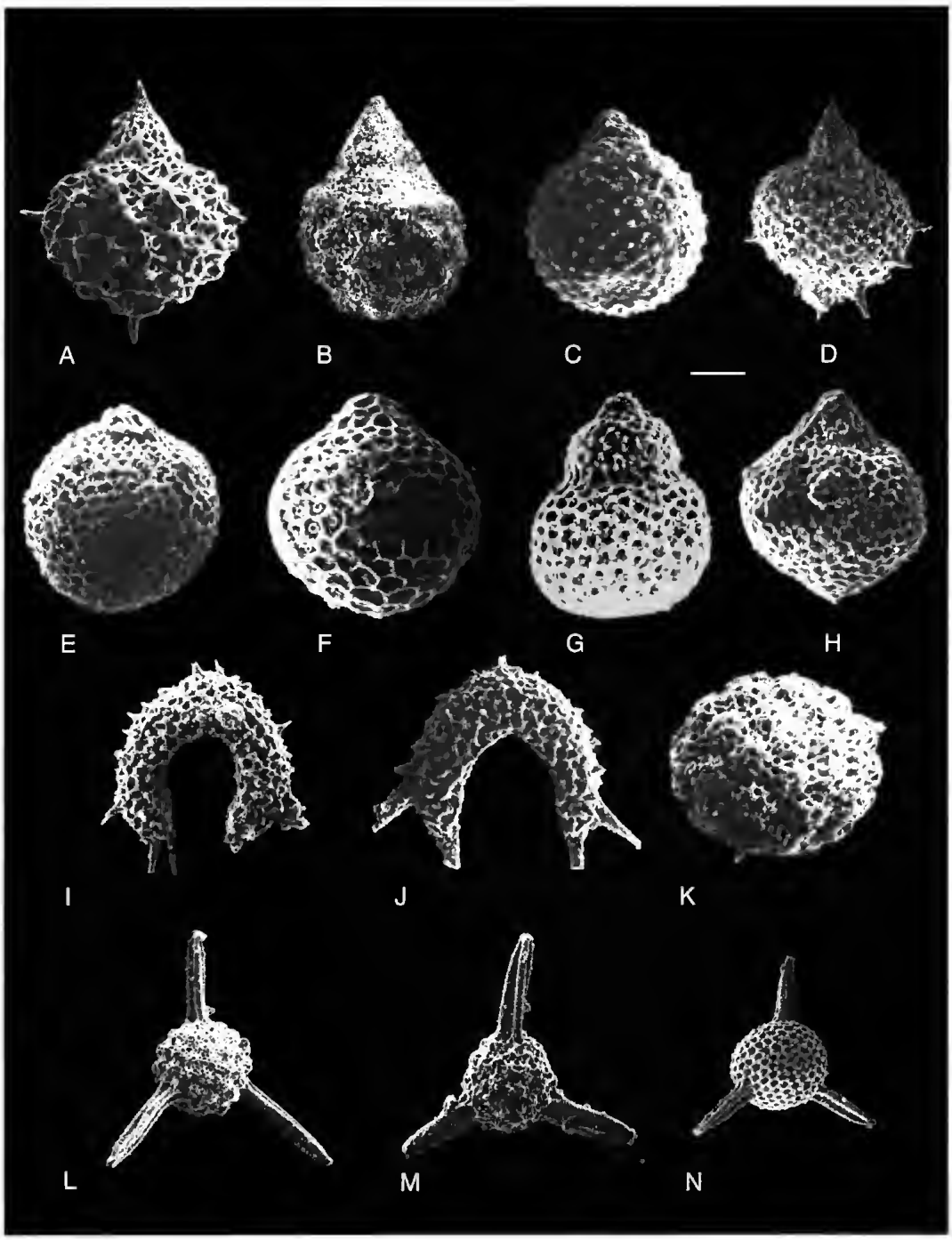

FIG. 6. — **A**, *Sethocapsa funatoensis* Aita (KEL 7); **B**, *Obesacapsula cetia* (Foreman) (KEL 23); **C**, *Tricolocapsa* sp. (KEL 25); **D**, *Sethocapsa leiostraca* Foreman (KEL 14); **E**, *Gongylothorax* sp. (KEL 25); **F**, *Cryptamphorella* sp. (KEL 25); **G**, *Tricolocapsa campana* Kiessling (KEL 18); **H**, *Zhamoidellum* sp. cf. *Z. ventricosum* Dumitrica (KEL 18); **I**, *Deviatus diamphidius* (Foreman) (KEL 20); **J**, *Deviatus diamphidius* (Foraman) (KEL 16); **K**, *Praeconosphaera sphaeroconus* (Rüst) (KEL 18); **L**, *Acaeniotyle diaphorogona* Foreman (KEL 16); **M**, *Acaeniotyle diaphorogona* Foreman (KEL 16); **N**, *Triactoma tithonianum* Rüst (KEL 16). Scale bar: A, D, 65 µm; B, L, 100 µm; C, E, F, G, 35 µm; H, 40 µm; I, K, 60 µm; J, 75 µm; M, 80 µm; N, 105 µm.

Cryptamphorella sp.
(Fig. 6F)

OCCURRENCE. — Sample KEL 25; in Calpionellid standard zone A subzone 2.

Genus *Tricolocapsa* Haeckel, 1881

Tricolocapsa campana Kiessling, 1995
(Fig. 6G)

Tricolocapsa campana Kiessling, 1995: 338, figs 7/1-4

OCCURRENCE. — Sample KEL 18; in Calpionellid standard zone B.

Tricolocapsa sp.
(Fig. 6C)

OCCURRENCE. — Sample KEL 25; Calpionellid standard zone A subzone 2.

Genus *Zhamoidellum* Dumitrica, 1970

Zhamoidellum sp. cf. ***Z. ventricosum***
Dumitrica, 1970
(Fig. 6H)

OCCURRENCE. — Samples KEL 14-18; in Calpionellid standard zone B.

Family POULPIDAE De Wever, 1981
Genus *Saitoum* Pessagno, 1977b

Saitoum sp.
(Fig. 7K)

OCCURRENCE. — Sample KEL 16-2; from middle of Calpionellid standard zone B to zone C.

Family AMPHIPYNDACIDAE Riedel, 1967
Subamily SYRINGOCAPSINAE
Foreman, 1973
Genus *Podobursa* Wisniowski, 1888

Podobursa sp.
cf. ***P. multispina*** Jud, 1994
(Fig. 7L)

OCCURRENCE. — Samples KEL 2-18; from Calpionellid standard zone B to zone C.

REMARKS
Poor preservation prevents the positive identification of this form as *Podobursa multispina*.

Podobursa polyacantha (Fischli, 1916)
(Fig. 7H)

Theosyringium acanthophorum Rüst var. *polyacanthus* Fischli, 1916 (*fide* Baumgartner *et al.*, 1995a): 47, fig. 41.
Podobursa polyacantha — Baumgartner *et al.* 1995a: 424, pl. 3174, figs 1-4(H).

OCCURRENCE. — Sample KEL 7; in upper part of Calpionellid standard zone B.

Suborder SPUMELLARIA Ehrenberg, 1875
Superfamily ACTINOMMACEA Haeckel, 1862
Family LEUGONIDAE Yang & Wang, 1990
emend. Dumitrica, 1995
Genus *Acaeniotyle* Foreman, 1973

Acaeniotyle diaphorogona
Foreman, 1973
(Fig. 6L, M)

Acaeniotyle diaphorogona Foreman, 1973: 258, pl. 2, figs 2-5. – Thurow 1988: 396, pl. 9, fig. 8. – Baumgartner *et al.* 1995a: 50, pl. 3090, figs 1-6.

OCCURRENCE. — Samples KEL 5-20; from the Jurassic-Cretaceous boundary to upper part of Calpionellid standard zone B.

Genus *Praeconosphaera* Yang, 1993

Praeconosphaera sphaeroconus
(Rüst, 1898)
(Fig. 6K)

Conosphaera sphaeroconus Rüst, 1898: 13, pl. 4, fig. 8.
Praeconosphaera sphaeroconus – Yang 1993: 105, pl. 17, figs 2, 6, 12, 16, 23. – Dumitrica *et al.* 1997: 21, pl. 3, fig. 3.

OCCURRENCE. — Samples KEL 7-23; from Calpionellid standard zone A subzone 3 to upper part of zone B.

Family PANTANELLIIDAE Pessagno, 1977a
emend. Pessagno & Blome, 1980

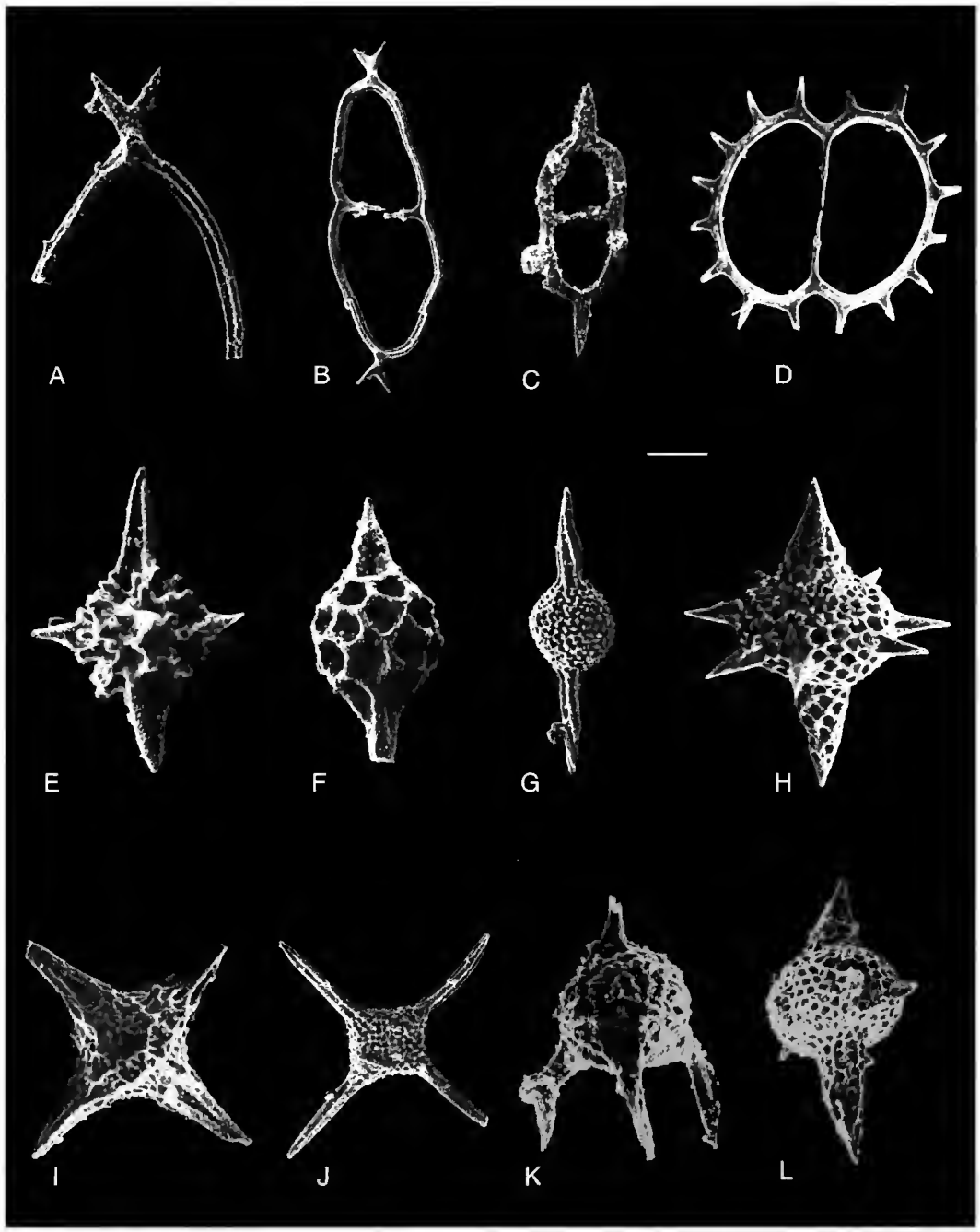

FIG. 7. — **A**, *Dicerosaturnalis dicranacanthos* (Squinabol) (KEL 16); **B**, *Dicerosaturnalis dicranacanthos* (Squinabol) (KEL 7); **C**, *Acanthocircus* sp. aff. *A. minimus* (Squinabol) (KEL 2); **D**, *Acanthocircus multidentatus* (Squinabol) (KEL 7); **E**, *Pantanellium berriasianum* Baumgartner (KEL 16); **F**, *Pantanellium* sp. (KEL 18); **G**, *Archaeospongoprunum patricki* Jud (KEL 20); **H**, *Podobursa polyacantha* (Fischli) (KEL 7); **I**, *Emiluvia omanensis* Kiessling (KEL 16); **J**, *Emiluvia pessagnoi* Foreman (KEL 20); **K**, *Saitoum* sp. (KEL 5); **L**, *Podobursa* sp. cf. *P. multispina* Jud (KEL 18). Scale bar: A, 70 µm; B, 160 µm; C, 105 µm; D, 95 µm; E, 50 µm; F, H, 60 µm; G, 90 µm; I, L, 80 µm; J, 155 µm; K, 35 µm.

Subfamily PANTANELLIINAE
Pessagno, 1977a
emend. Pessagno & Blome, 1980
Genus *Pantanellium* Pessagno, 1977a
emend. Pessagno & Blome, 1980

Pantanellium berriasianum
Baumgartner, 1984
(Fig. 7E)

Pantanellium (?) *berriasianum* Baumgartner, 1984: 776-777, pl. 6, figs 14-15.
Pantanellium berriasianum – Jud 1994: 89, pl. 15, figs 5-6. – Baumgartner *et al.* 1995a: 368, pl. 3280, figs 1(H)-2.

OCCURRENCE. — Samples KEL 7-17; from lower to upper part of Calpionellid standard zone B.

Pantanellium sp.
(Fig. 7F)

OCCURRENCE. — Samples KEL 2-25; from Calpionellid standard zone A subzone 2 to zone C.

REMARKS
Poor preservation hinders further identification of this specimen.

Family XIPHOSTYLIDAE Haeckel, 1881
emend. Pessagno & Yang,
in Pessagno *et al.*, 1989
Genus *Triactoma* Rüst, 1885

Triactoma tithonianum Rüst, 1885
(Fig. 6N)

Triactoma tithonianum Rüst, 1885 (*fide* Baumgartner *et al.*, 1995a): 289, pl. 28, fig. 5. – Jud 1994: 115, pl. 23, figs 10-11. – Baumgartner *et al.* 1995a: 52, pl. 3097, figs 1-3 (H).

OCCURRENCE. — Sample KEL 16; in Calpionellid standard zone B.

Superfamily PYLONIACEA Haeckel, 1881
emend. Dumitrica, 1989
Family ORBICULIFORMIDAE Pessagno, 1973
emend. Dumitrica, 1995
Subfamily EMILUVIINAE Dumitrica, 1995
Genus *Emiluvia* Foreman, 1973

Emiluvia omanensis Kiessling, 1995
(Fig. 7I)

Emiluvia omanensis Kiessling, 1995: 330, figs 6/5-8. – Dumitrica *et al.* 1997: 27, pl. 4, figs 2, 4.

OCCURRENCE. — Samples KEL 7-16; in Calpionellid standard zone B.

Emiluvia pessagnoi Foreman, 1973
(Fig. 7J)

Emiluvia pessagnoi Foreman, 1973: 262, pl. 8, fig. 6.
Emiluvia pessagnoi s.l. – Jud 1994: 77, pl. 10, figs 1, 2. – Baumgartner *et al.* 1995a: 206, pl. 3066, figs 1, 2.

OCCURRENCE. — Samples KEL 20-21; on Jurassic-Cretaceous boundary.

Family TRITRABIDAE Baumgartner, 1980
Genus *Deviatus* Li, 1986

Deviatus diamphidius (Foreman, 1973)
(Fig. 6I, J)

Paronaella (?) *diamphidia* Foreman, 1973: 262, pl. 8, figs 3,4.
Foremanella diamphidia – Baumgartner 1984: 765, pl. 6, fig. 18.
Deviatus diamphidius – O'Dogherty 1994: 345, pl. 64, fig. 14. – Dumitrica *et al.* 1997: 28, pl. 4, fig. 3.
Deviatus diamphidius diamphidius – Baumgartner *et al.* 1995a: 172, pl. 3112, figs 1-6(H).

OCCURRENCE. — Samples KEL 2-20; from lower part of Calpionellid standard zone B to zone C.

Genus *Tritrabs* Baumgartner, 1980

Tritrabs ewingi gr. (Pessagno, 1971)
(Fig. 8B)

Paronaella (?) *ewingi* Pessagno, 1971: 47, pl. 19, figs 2-5.
Tritrabs ewingi s.l. – Baumgartner *et al.* 1995a: 606, pl. 3113, figs 1-8(H).
Tritrabs ewingi gr. – Jud 1994: 116, pl. 23, figs 12-13.
Tritrabs ewingi – Dumitrica *et al.* 1997: 27, pl. 4, fig. 1. – Hull 1997: 4, pl. 19, fig. 9, 12.

OCCURRENCE. — Samples 2-7; from upper part of Calpionellid standard zone B to zone C.

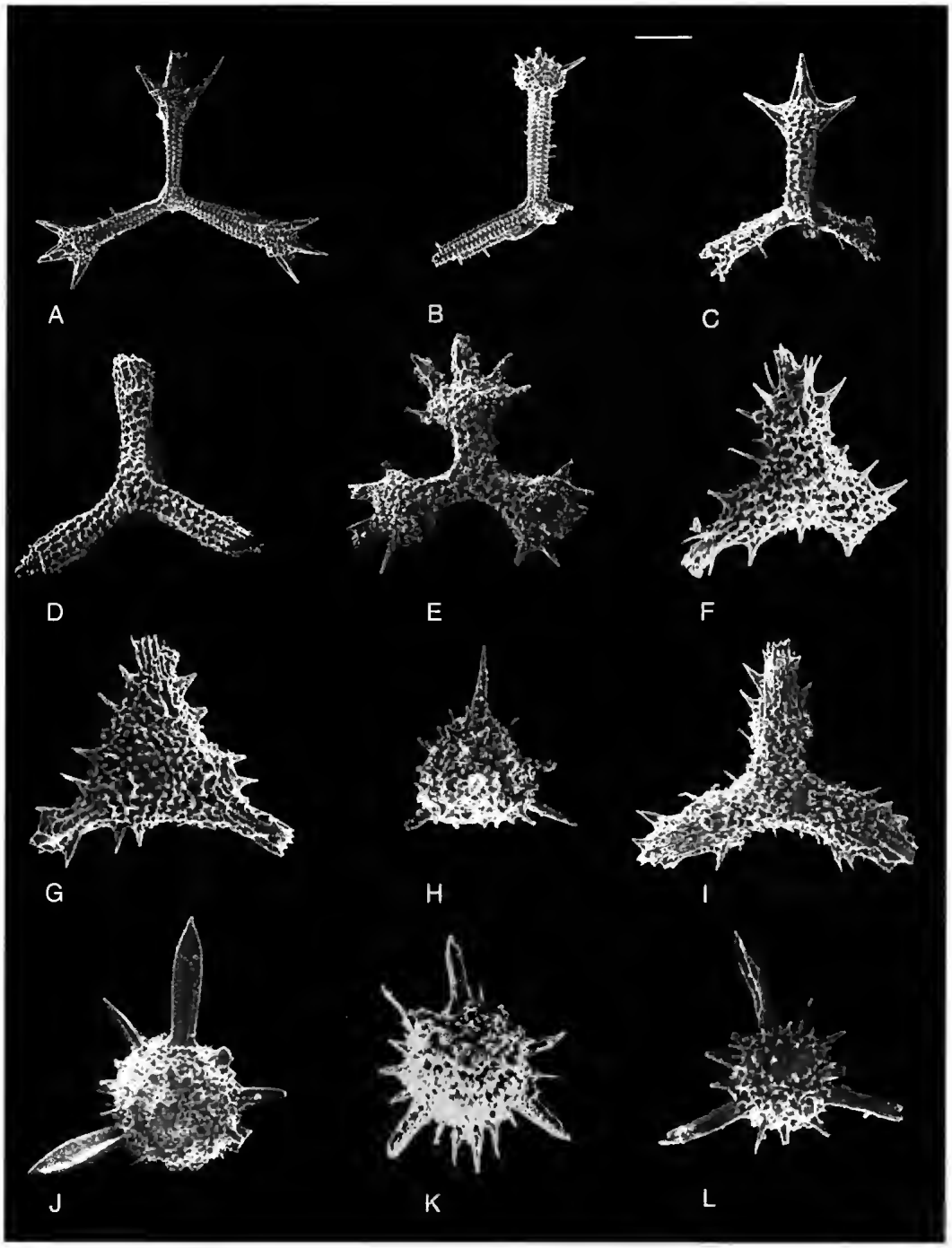

FIG. 8. — **A**, *Halesium sexangulum* Pessagno *sensu* Steiger (KEL 7); **B**, *Tritrabs ewingi* gr. (Pessagno) (KEL 18); **C**, *Halesium irregularis* Steiger (KEL 16); **D**, *Angulobracchia* (?) *portmanni* s.l. Baumgartner (KEL 16); **E**, *Halesium* (?) sp. (KEL 20); **F**, *Paronaella* (?) sp. cf. *P. tubulata* Steiger (KEL 7); **G**, *Paronaella* (?) sp. cf. *P. tubulata* Steiger (KEL 7); **H**, *Pyramispongia barmsteinensis* (Steiger) (KEL 20); **I**, *Paronaella* (?) *tubulata* Steiger (KEL 7); **J**, *Becus triangulocentrum* Dumitrica (KEL 16); **K**, *Alievium nodulosum* Dumitrica (KEL 20); **L**, *Alievium regulare* (Wu & Li) (KEL 18). Scale bar: A, 120 µm; B, 155 µm; C, 85 µm; D, 145 µm; E, 110 µm; F, 90 µm; G, J, 75 µm; H, I, K, L, 65 µm; K, 105 µm.

Superfamily SATURNALIACEA
Deflandre, 1953
Family SATURNALIDAE Deflandre, 1953
Subfamily SATURNALINAE Deflandre, 1953
Genus *Acanthocircus* Squinabol, 1903

Acanthocircus multidentatus
(Squinabol, 1914)
(Fig. 7D)

Saturnalis multidentatus Squinabol, 1914: 298, pl. 23 [4], figs 11, 12.
Acanthocircus multidentatus – Pessagno 1977b: 32, pl. 2, figs 15, 20. – O'Dogherty 1994: 255, pl. 44, figs 7-10.

OCCURRENCE. — Samples KEL 7-16; from lower to upper part of Calpionellid standard zone B.

Acanthocircus sp.
aff. ***A. minimus*** (Squinabol, 1914)
(Fig. 7C)

OCCURRENCE. — Samples KEL 2-23; from Calpionellid standard zone A subzone 3 to zone C.

REMARKS
Our specimen differs from *A. ellipticus* (Squinabol, 1903) and *A. bispinus* (Yao, 1972) by its smaller size and narrower ring. It more closely resembles *A. minimus* (Squinabol, 1914) although it has a more rectangular outline and flatter ring.

Genus *Dicerosaturnalis*
Dumitrica & Jud, 1997

Dicerosaturnalis dicranacanthos
(Squinabol, 1914)
(Fig. 7A, B)

Saturnalis dicranacanthos Squinabol, 1914: 289, pl. 22, figs 4-7; pl. 23, fig. 8.
Acanthocircus dicranacanthos – Foreman 1975: 610, pl. 2D, figs 5-6. – Hull 1997: 29, pl. 9, fig. 3, 4.
Acanthocircus trizonalis dicranacanthos – Baumgartner *et al.* 1995a: 72, pl. 3087, figs 1-8(H).
Dicerosaturnalis dicranacanthos – Dumitrica *et al.* 1997: 18, pl. 1, fig. 15.

OCCURRENCE. — Sample KEL 2-21; from Jurassic-Cretaceous boundary to Calpionellid standard zone C.

Superfamily SPONGODISCACEA
Haeckel, 1862
Family CAVASPONGIDAE Pessagno, 1973
Genus *Pyramispongia* Pessagno, 1973

Pyramispongia barmsteinensis
(Steiger, 1992)
(Fig. 8H)

Nodotetraedra barmsteinensis Steiger, 1992: 33, pl. 4, figs 9-14.
Pyramispongia barmsteinensis – Baumgartner *et al.* 1995a: 464, pl. 6109, figs 1-4. – Dumitrica *et al.* 1997: 26, pl. 4, fig. 12.

OCCURRENCE. — Samples KEL 2-20; from Jurassic-Cretaceous boundary to Calpionellid standard zone C.

Family PATULIBRACCHIDAE Pessagno, 1971
emend. Baumgartner, 1980
Genus *Angulobracchia* Baumgartner, 1980

Angulobracchia (?) ***portmanni*** s.l.
Baumgartner, 1984
(Fig. 8D)

Angulobracchia (?) *portmanni* Baumgartner, 1984: 757, pl. 2, fig. 3.
Angulobracchia (?) *portmanni* s.l. – Baumgartner *et al.* 1995a: 88, pl. 6121, figs 1-4.
Angulobracchia (?) *portmanni* – Dumitrica *et al.* 1997: 30, pl. 4, fig. 16.

OCCURRENCE. — Samples KEL 7-16; from lower to upper part of Calpionellid standard zone B.

Genus *Halesium* Pessagno, 1971
emend. Baumgartner, 1984

Halesium sexangulum
Pessagno, 1971 *sensu* Steiger, 1992
(Fig. 8A)

Halesium sexangulum Pessagno, 1971: 25, pl. 1, figs 5-6; pl. 2, figs 1-6. – Steiger 1992: 47, pl. 11 figs 1, 2.

OCCURRENCE. — Samples KEL 2-7; from upper part of Calpionellid standard zone B to zone C.

Halesium irregularis
Steiger, 1992
(Fig. 8C)

Halesium irregularis Steiger, 1992: 47, pl. 11, figs 3-5.

OCCURRENCE. — Sample KEL 16; in Calpionellid standard zone B.

Halesium (?) sp.
(Fig. 8E)

OCCURRENCE. — Samples KEL 9-20; from Jurassic-Cretaceous boundary to upper part of Calpionellid standard zone B.

Genus *Paronaella* Pessagno, 1971
emend. Baumgartner, 1980

Paronaella (?) ***tubulata***
Steiger, 1992
(Fig. 8I)

Paronaella (?) *tubulata* Steiger, 1992: 45, pl. 10, fig. 10. – Jud 1994: 91, pl. 15, figs 18-19. – Baumgartner *et al.* 1995a: 400, pl. 5183, figs 1-5 (H).

OCCURRENCE. — Samples KEL 2-7; from upper part of Calpionellid standard zone B to zone C.

Paronaella sp.
cf. ***P.*** (?) ***tubulata*** Steiger, 1992
(Fig. 8F, G)

OCCURRENCE. — Samples KEL 2-7; from upper part of Calpionellid standard zone B to zone C.

Family PSEUDOAULOPHACIDAE Riedel, 1967
emend. Dumitrica, 1997
Genus *Alievium* Pessagno, 1972

Alievium nodulosum Dumitrica, 1997
(Fig. 8K)

Alievium nodulosum Dumitrica, 1997: 224, pl. 3, fig. 9.

OCCURRENCE. — Sample KEL 20; on Jurassic-Cretaceous boundary.

Alievium regulare (Wu & Li, 1982)
(Fig. 8L)

Praeconocaryomma regulare Wu & Li, 1982 : 65, pl. 1, figs 1,3.
Alievium helenae – Schaaf 1981: 431, pl. 7, fig. 9; (*non*) pl. 10, fig. 2a-b. – Baumgartner *et al.* 1995a: 80, pl. 3228, figs 1,3,4, non 2,5.
Alievium regulare – Dumitrica 1997: 221, pl. 2, figs 12-14; pl. 3 figs 1-3, 5.

OCCURRENCE. — Samples KEL 2-23; from Calpionellid standard zone A subzone 3 to zone C.

Genus *Becus* Wu, 1986
Becus triangulocentrum
Dumitrica, 1997
(Fig. 8J)

Becus triangulocentrum Dumitrica, 1997: 216, pl. 1, figs 8-9; pl. 2, figs 1, 2, 4, ?3, ?5, ?6.
Alievium helenae – Baumgartner *et al.* 1995a: 80, pl. 3228 (*pars*), fig. 2, *non* 1-4 = *Alievium regulare*, 5 = *Becus helenae*.

OCCURRENCE. — Samples KEL 16; in Calpionellid standard zone B.

REMARKS
Our specimen differs from *Becus helenae* (Schaaf, 1981) by having three nodes at the center of the circle of nodes on each side. It differs from *B. gemmatus* Wu, 1986 by having twelve nodes composing a circle rather than nine. It more closely resembles *B. triangulocentrum* Dumitrica, 1997 by having twelve nodes making up a circle on each face and by having three nodes in the central area inside the circle.

Family SPONGURIDAE Haeckel, 1862
Genus *Archaeospongoprunum* Pessagno, 1973

Archaeospongoprunum patricki
Jud, 1994
(Fig. 7G)

Archaeospongoprunum patricki Jud, 1994: 63, pl. 4, figs 2-4. – Baumgartner *et. al.* 1995a: 110, pl. 5042, figs 1(H)-4. – Dumitrica *et al.* 1997: 21, pl. 2, fig. 3.

OCCURRENCE. — Samples KEL 2-23; from Calpionellid standard zone A subzone 3 to C.

CONCLUSIONS

The resolution of radiolarian bioevents increases with the fine sampling interval in section KEL (15-20 meters) and the stepwise initial occurrence of Cretaceous radiolarian taxa is accentuated. This gradual appearance of the taxa is probably an artifact of selective preservation because taxa such as *Alievium regulare*, *Dicerosaturnalis dicranachanthos*, *Deviatus diamphidius*, *Acaeniotyle diaphorogona*, *Archaeodictyomitra apiarium*, *Emiluvia pessagnoi*, *Pantanellium berriasianum*, and *Hsuum raricostatum*, among others, appear at chronostratigraphically lower levels in other European sections (see Baumgartner *et* al. 1995a) than they do in section KEL (Fig. 4). Selective preservation, the lack of a sudden change/turnover in radiolarian fauna at the Jurassic-Cretaceous boundary and only two samples from the latest Tithonian make the delineation of the Jurassic-Cretaceous boundary impossible in section KEL at this time. Despite preservational problems, a typical Tethyan radiolarian fauna consisting of 33 genera and 36 species are illustrated from Turkey for the first time.

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Late Cretaceous (late Campanian-early Maastrichtian) radiolarian biogeography; a review

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ABSTRACT
Some characteristic species of Late Cretaceous radiolarians from central Japan and the world are discussed. With respect to the relation between radiolarian distribution and latitude, *Amphipyndax enesseffi* Foreman, *Theocampe abschnitta* (Empson-Morin), *Myllocercion acineton* Foreman, and *Dictyomitra lamellicostata* Foreman were restricted to the low to intermediate latitudes. *Lithomelissa heros* Campbell & Clark, *Lithomelissa hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark) would tend to be cosmopolitan; however, only in the circum-Pacific region, they were apparently confined to northeastern Asia, northwestern North America, and the Antarctic. The existence of the distribution of the Late Cretaceous radiolarians could be explained by oceanic circulation patterns and it was important in determining Late Cretaceous provincial boundaries of radiolarians.

KEY WORDS
Late Cretaceous,
radiolarians,
Tethys,
Atlantic,
Pacific,
oceanic circulation.

RÉSUMÉ

Biogéographie des radiolaires du Crétacé supérieur (Campanien supérieur-Maastrichtien inférieur) : bilan.

Quelques espèces caractéristiques du Crétacé supérieur du Japon central et du monde sont discutées. Tenant compte des distributions paléolatitudinales, il apparaît que *Amphipyndax enesseffi* Foreman, *Theocampe abschnitta* (Empson-Morin), *Myllocercion acineton* Foreman, and *Dictyomitra lamellicostata* Foreman sont restreints aux basses latitudes ou intermédiaires, alors que *Lithomelissa heros* Campbell & Clark, *Lithomelissa hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark) tendraient à être cosmopolites. Néanmoins, dans les régions circum-Pacifique, ils sont apparemment confinés au Nord-Est de l'Asie, au nord-ouest de l'Amériquedu Nord et à l'Antarctique. L'existence de cette distribution au Crétacé supérieur pourrait être expliquée par des courants océaniques qui ont déterminé les limites des provinces fauniques de radiolaires à cette époque.

MOTS CLÉS
Crétacé supérieur, radiolaires, mer mésogéenne, Atlantique, Pacifique, circulation océanique.

INTRODUCTION

Radiolaria are effective indicators of various oceanic environments: paleoceanographic, paleoecologic, bathymetric, etc. Since Haeckel (1887), many paleobiogeographic studies of radiolarians have been done during the past 100 years. However, most have been restricted to the Cenozoic (e.g., Casey 1971; Goll & Bjørklund 1971; Petrushevskaya 1971), and very little has been published on radiolarian paleobiogeography from the Mesozoic. Pessagno (1976) established a radiolarian zonation for the Upper Cretaceous portion of the Great Valley sequence of Northern California and stated that radiolarian species common to the Upper Cretaceous strata of the Tethyan, Boreal, and Austral Faunal Provinces are eurybathic and would tend to be more cosmopolitan. However, commencing with the study of Empson-Morin (1984), Upper Cretaceous radiolarians have been appreciated as valuable biogeographic tools. She described the Upper Cretaceous radiolarians as effective environmental indicators showing variations in response to depth and/or latitude.

Recently, a preliminary study by Takahashi & Ishii (1993) stated that the Upper Cretaceous (late Campanian-early Maastrichtian) strata of central Japan include two characteristic radiolarian faunas. I have noticed in the Late Cretaceous Northwestern Pacific Ocean an example showing two parallel distributions of characteristic radiolarian faunas; the similarity of the northern Northwestern Pacific fauna and the lack of similarity of the southern Northwestern Pacific fauna to species of the California Upper Cretaceous (e.g., Campbell & Clark 1944).

LATE CAMPANIAN TO EARLY MAASTRICHTIAN RADIOLARIANS FROM CENTRAL JAPAN

GEOLOGIC SETTING AND RADIOLARIAN FOSSILS OF THE SHOYA FORMATION, NORTHERN CENTRAL JAPAN

The Shoya Formation (Watanabe 1958) is exposed in an area approximately 0.5 km wide and 4.5 km long, and located 100 km northwest of Tokyo (Fig. 1). It consists of three fining-upward cyclic sequences of marine sedimentary rocks about 600 m in total thickness, lacking pelagic interbeds. The lower and middle parts of each sequence are composed of poorly-sorted, black, medium- or fine-grained sandstone, which grade upward into well-sorted, bedded, dark gray sandstone. The upper part of each sequence is composed of alternations of mudstone and sandstone with dark gray, siliceous mudstone. The siliceous mudstone frequently contains thin (several milli-

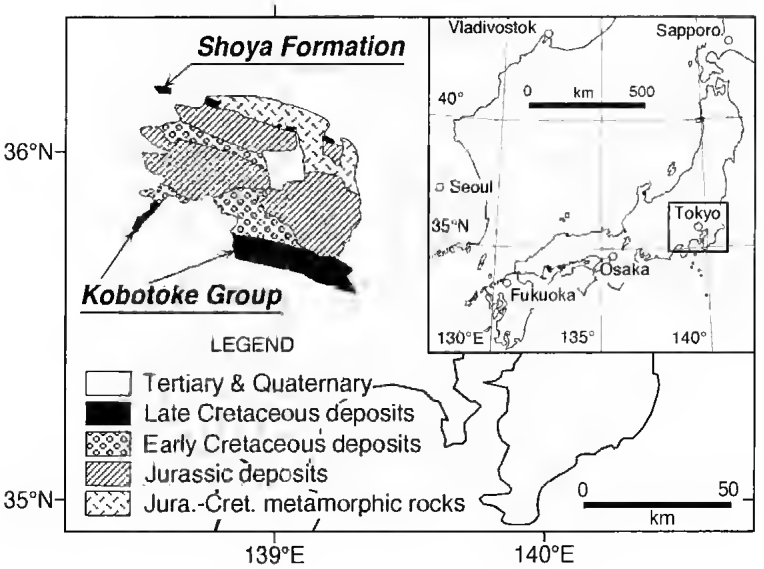


FIG. 1. — Index map of the study area showing the position of the Shoya Formation and the Kobotoke Group in central Japan.

meters) layers of interbedded, greenish-gray, tuffaceous mudstone or tuff. Some sandstone units contain abundant, yet poorly preserved molluscs, including *Spondylus japonicus*, *Cardium*(?), *Ostrea*, other pelecypods, brachiopods, and corals (Amano & Marui 1958). Based on tectonic configuration, litho- and bio-facies, the Shoya Formation is interpreted as a typical forearc sequence at the eastern margin of the Asian Continent (Ishii & Takahashi 1993).

Radiolarian fossils were encountered in the dark gray or black siliceous mudstone parts of the strata. The radiolarian assemblage contains 17 species belonging to 10 genera (Table 1), some of which are shown in Fig. 2A-S. The assemblage rarely contained *Amphipyndax tylotus* Foreman and *A. enesseffi* Foreman, and is characterized by the occurrence of *Lithomelissa heros* Campbell & Clark, *L. hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark).

GEOLOGIC SETTING AND RADIOLARIAN FOSSILS OF THE KOBOTOKE GROUP, SOUTHERN CENTRAL JAPAN

The Kobotoke Group (Makino 1973; Sakai 1987) is exposed in an area approximately 10 km wide and 70 km long, and located 50-100 km west of Tokyo (Fig. 1). It is composed of rhythmically alternating beds (several centimeters thick) of fine- to medium-grained arkosic sandstone and black mudstone, occasionally including chert and limestone blocks and conglomerate lenses in the mudstone dominant part. The chert is mostly red and rhythmically bedded and the limestone is dark gray in color. The conglomerate is composed of pebbles of limestone, chert, sandstone, and mudstone within a sandy matrix, and they are found in small bodies sporadically scattered in the sandstone layers.

The strata show normal graded bedding and are steeply dipping northward in a monoclinal structure, nevertheless, the geological ages of the southern beds are younger than those of the northern beds (Ishii *et al.* 1990). These features, the overall younging towards the south by repetition of the strata within imbricate thrusts, suggest a typical strata distribution for an accretionary prism (Ishii & Takahashi 1993).

Radiolarian fossils were encountered in the siliceous, dark gray or black mudstone parts of the strata. The radiolarian assemblage contains 11 species belonging to 6 genera (Table 1), some of which are shown in Fig. 3A-M. The assemblage is characterized by the predominant occurrence of *Amphipyndax tylotus* Foreman and

TABLE 1. — Occurrence and relative abundance of radiolarians of the Shoya Formation and the Kobotoke Group. Radiolarian abundances are categorized as common (C) and rare (R). Plus (+) means presence, but recognized with such difficulty that no estimate of abundance could be made.

Taxon	Shoya Formation					Kobotobe G.	
	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	St-1	St-2
Amphipyndax alamedaensis (Campbell & Clark)	–	C	–	–	–	R	R
A. enesseffi Foreman	R	–	–	R	–	C	R
A. plousios Foreman	–	C	–	R	–	–	–
A. stockl (Campbell & Clark)	C	C	+	C	+	C	C
A. tylotus Foreman	–	C	+	C	–	C	C
Archaeospongoprunum salumi Pessagno	C	–	–	C	–	–	–
A. stocktonensis Pessagno	–	–	–	R	–	–	–
Cornutella californica Campbell & Clark	–	–	–	R	–	R	–
Dictyomitra andersoni (Campbell & Clark)	R	C	–	C	+	C	C
D. lamellicostata Foreman	–	–	–	–	–	C	C
D. multicostata Pessagno	C	C	+	C	–	C	C
Eribotrys anax Foreman	–	–	–	R	–	–	–
Lithomelissa heros Campbell & Clark	–	–	–	C	–	–	–
L. hoplites Foreman	–	–	–	C	+	–	–
Myllocercion acineton Foreman	–	–	–	–	–	C	–
Praeconocaryomma dauerhafta (Empson-Morin)	–	–	–	–	–	R	–
Pseudoaulophacus floresensis Pessagno	–	–	–	–	–	R	R
Rhopalosyringium magnificum Campbell & Clark	–	C	–	–	–	R	C
Saturniforma brionesensis Pessagno	–	–	–	C	–	–	–
sciadiocapsid	R	–	–	C	–	–	–
Stichomitra asymbatos Foreman	R	C	–	R	–	C	R
S. livermorensis (Campbell & Clark)	–	C	–	C	–	–	–
Theocampe abschnitta (Empson-Morin)	–	–	–	–	–	C	R
T. altamontensis (Campbell & Clark)	–	–	–	C	–	–	–
Theocapsomma amphora Campbell & Clark	R	C	–	C	–	–	–

A. enesseffi Foreman, and also characterized by the occurrence of *Theocampe abschnitta* (Empson-Morin), *Dictyomitra lamellicostata* Foreman, and *Myllocercion acineton* Foreman.

AGE ASSIGNMENT

The two radiolarian assemblages from the Shoya Formation and the Kobotoke Group have some differences in their components. However, these assemblages contain common and/or individual typical species of the *Amphipyndax tylotus* zone (Foreman 1977; Sanfilippo & Riedel 1985). For example, the first appearances of *Lithomelissa hoplites* and *Theocampe abschnitta* are included near the base of the *A. tylotus* zone. The top of the zone is defined as the Maastrichtian/Danian boundary recognized by the last occurrences of *A. tylotus*, *L. hoplites*, and *Dictyomitra lamellicostata* (Foreman 1968, 1977; Sanfilippo & Riedel 1985). With respect to the other species, the first appearances of *Lithomelissa heros*, *Theocampe altamontensis*, and *Myllocercion acineton* are Campanian (Pessagno 1976; Foreman 1978; Taketani 1982; Empson-Morin 1981; Sanfilippo & Riedel 1985), whereas *Stichomitra livermorensis* first occurs in the Coniacian (Moore 1973). The final occurrences of these species also correspond to the top of the *A. tylotus* zone at the Maastrichtian/Danian boundary (Foreman 1968, 1978; Sanfilippo & Riedel 1985).

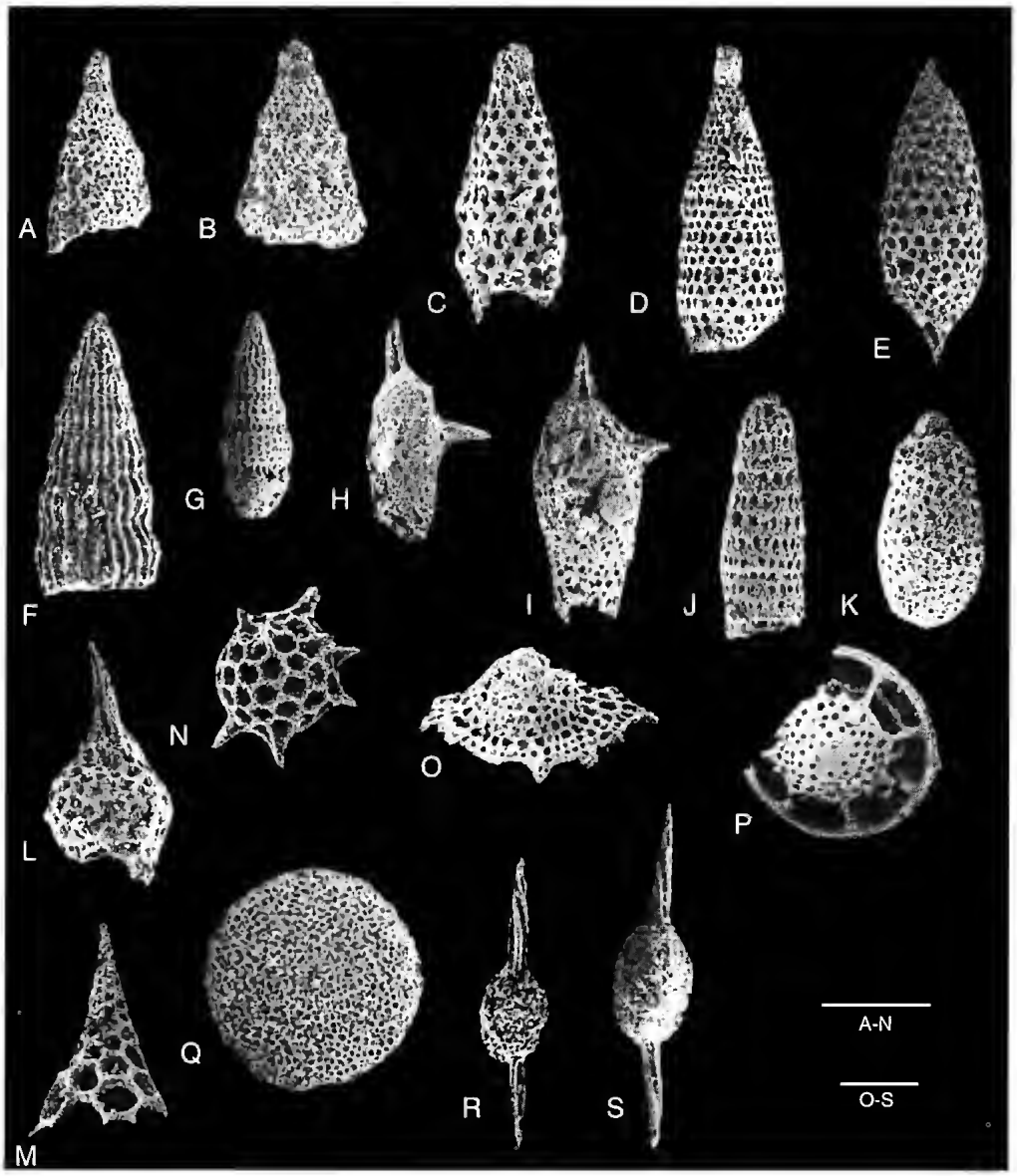


FIG. 2. — Late Campanian-early Maastrichtian radiolarian fauna from the Shoya Formation, northern central Japan. **A**, *Amphipyndax tylotus* Foreman; **B**, *Amphipyndax enesseffi* Foreman; **C**, *Amphipyndax alamedaensis* (Campbell & Clark); **D**, *Amphipyndax stocki* (Campbell & Clark); **E**, *Stichomitra livermorensis* (Campbell & Clark); **F**, *Dictyomitra multicostata* Pessagno; **G**, *Dictyomitra andersoni* (Campbell & Clark); **H**, *Lithomelissa heros* Campbell & Clark; **I**, *Lithomelissa hoplites* Foreman; **J**, *Theocampe altamontensis* (Campbell & Clark); **K**, *Theocapsomma amphora* Campbell & Clark; **L**, *Rhopalosyringium magnificum* Campbell & Clark; **M**, *Cornutella californica* Campbell & Clark; **N**, gen. sp. indet.; **O**, Sciadiocapsid gen. sp. indet.; **P**, *Saturniforma brionesensis* Pessagno; **Q**, *Orbiculiforma* sp.; **R**, *Archaeospongoprunum salumi* Pessagno; **S**, *Archaeospongoprunum stocktonensis* Pessagno. Scale bars: 0.1 mm

Therefore, these species of both assemblages recovered from the Shoya Formation and the Kobotoke Group represent the *Amphipyndax tylotus* zone which is indicative of a range from the late Campanian to the early Maastrichtian in age (Foreman 1977, 1978; Sanfilippo & Riedel 1985).

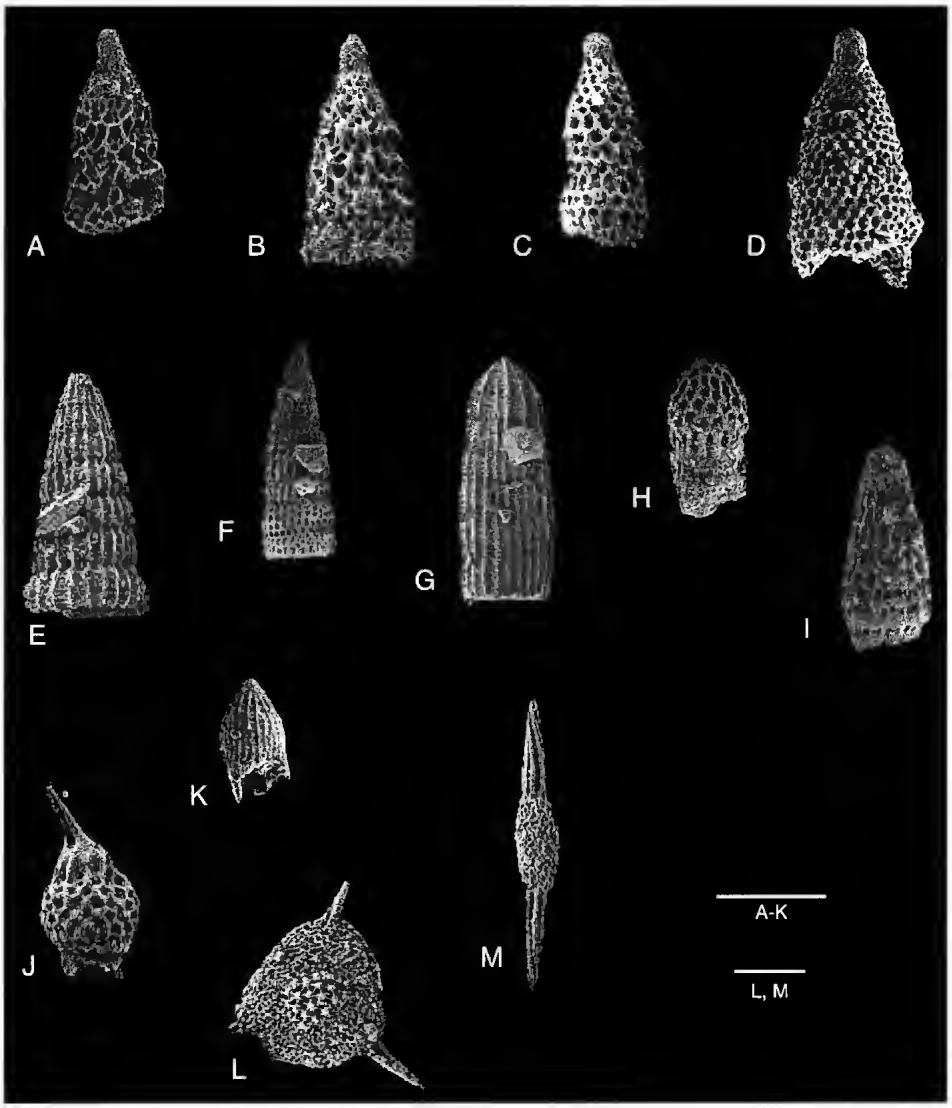


FIG. 3. — Late Campanian-early Maastrichtian radiolarian fauna from the Kobotoke Group, southern central Japan. **A**, *Amphipyndax tylotus* Foreman; **B**, *Amphipyndax enesseffi* Foreman; **C**, *Amphipyndax alamedaensis* (Campbell & Clark); **D**, *Amphipyndax stocki* (Campbell & Clark); **E**, *Dictyomitra multicostata* Pessagno; **F**, *Dictyomitra andersoni* (Campbell & Clark); **G**, *Dictyomitra lamellicostata* Foreman; **H**, *Theocampe abschnitta* (Empson-Morin); **I**, *Theocampe* sp.; **J**, *Rhopalosyringium magnificum* Campbell & Clark; **K**, *Myllocercion acineton* Foreman; **L**, *Pseudoaulophacus floresensis* Pessagno; **M**, *Archaeospongoprunum* sp. Scale bars: 0.1 mm.

PALEOBIOGEOGRAPHIC DISTRIBUTIONS OF LATE CAMPANIAN-EARLY MAASTRICHTIAN RADIOLARIANS

Selected pairings of the assemblages from the Shoya Formation and the Kobotoke Group were compared by means of a similarity index (Jaccard Coefficient: Table 2). The results show that the pairings between the Kobotoke Group (St-1 and St-2) and the Shoya Formation (Sh-1, Sh-2, and

TABLE 2. — A matrix of similarity values (JI: Jaccard index) for comparisons of radiolarian assemblages from each sample.

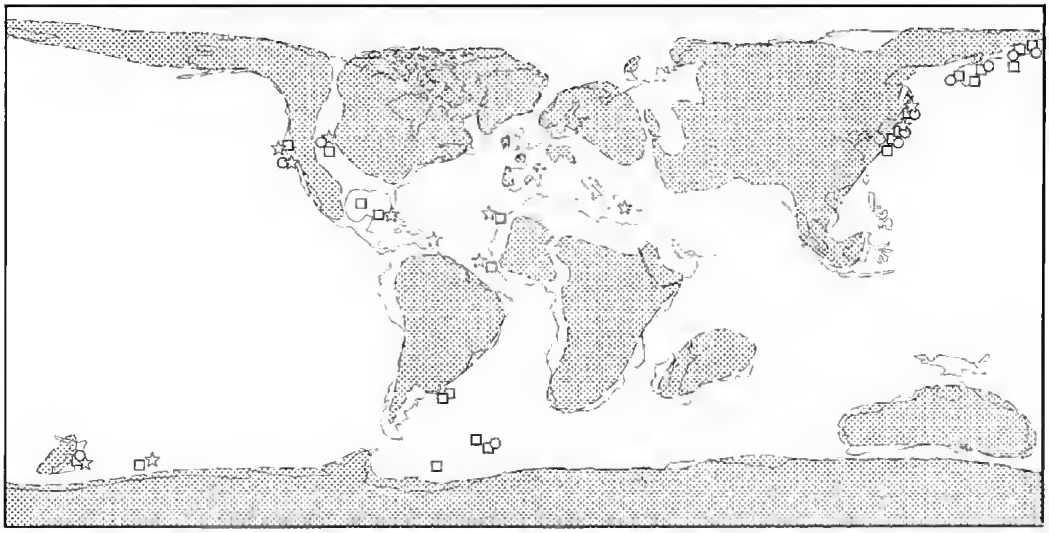
	Shoya F.		Kobotobe G.	
	Sh-2	Sh-4	St-1	St-2
Sh-1	0.38	0.44	0.29	0.36
Sh-2		0.40	0.41	0.50
Sh-4			0.28	0.26
St-1				0.78

Sh-4) yielded somewhat lower values than did pairings from within each one. Namely, each assemblage is characterized by different species. For example, the assemblage from the Shoya Formation is characterized by the occurrence of *Lithomelissa heros* Campbell & Clark, *Lithomelissa hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark), whereas the one from the Kobotoke Group is characterized by the occurrence of *Theocampe abschnitta* (Empson-Morin), *Dictyomitra lamellicostata* Foreman, and *Myllocercion acineton* Foreman.

Radiolarians from each sample occur in the same siliceous mudstone lithofacies, and the rock samples were carefully taken from non-folded, non-overturned, and non-metamorphosed parts. Furthermore, in spite of varied states of preservation, each radiolarian assemblage has its own characteristic species, although the number of skeletons may differ. Thus, it is suggested that the differences in components between the two Late Cretaceous radiolarian assemblages may have been caused largely by oceanic environment. In this study, I attempt to distinguish the paleobiogeographic distributions of the seven characteristic species of the radiolarian faunas, and examine the differences in components and their possible causes from their worldwide distributions in Late Cretaceous time. The localities of radiolarians are illustrated in Figs 4, 5.

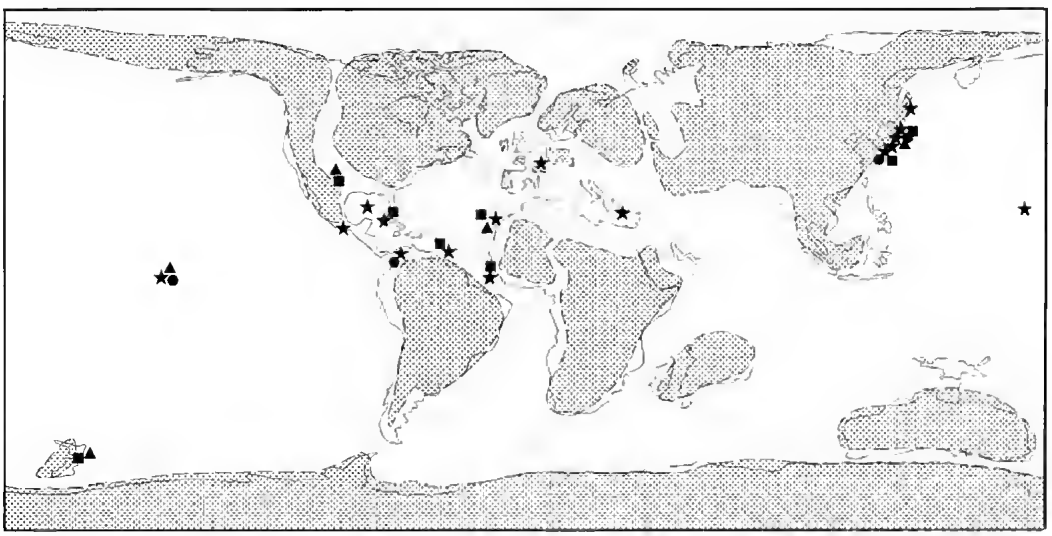
Lithomelissa hoplites (Fig. 2J) was reported from California (Foreman 1968), the mid-Atlantic Ocean (Foreman 1977), New Zealand (Hollis 1997), and Southwest Japan (Yamasaki 1987). *Lithomelissa heros* (Fig. 2I) was reported from California (Campbell & Clark 1944; Foreman 1968; Pessagno 1976), New Zealand (Hollis 1997), and the mid-Atlantic Ocean (Foreman 1978). *Lithomelissa* sp. were reported from the northeast coast of New Zealand (Ballance *et al.* 1989; Hollis 1997), Southwest Japan (Yamasaki 1987), and Hokkaido (Iwata & Tajika 1986). *Theocampe altamontensis* (Fig. 2K) was reported from the northeast coast of New Zealand (Ballance *et al.* 1989; Hollis 1997), the south Atlantic Ocean (Foreman 1977), the Antarctic Ocean (Ling & Lazarus 1990; Ling 1991), California (Campbell & Clark 1944), Southwest Japan (Muramatsu 1986; Yamasaki 1987), and the Bering Region (Vishnevskaya 1986). *Stichomitra livermorensis* (Fig. 2F) was reported from California (Campbell & Clark 1944; Foreman 1968), the Bering Region (Vishnevskaya 1986), the Antarctic Ocean (Ling 1991), New Zealand (Hollis 1997), Southwest Japan (Suyari 1986; Yamasaki 1987), and Hokkaido (Iwata & Tajika 1986, 1989). *Amphipyndax enesseffi* (Figs 2C, 3C) was reported from the mid-Pacific Ocean (Moore 1973; Empson-Morin 1981), California (Pessagno 1969), the mid-Atlantic Ocean (Foreman 1977, 1978; Empson-Morin 1984), Southwest Japan (Suyari & Hashimoto 1985; Muramatsu 1986; Suyari 1986; Yamasaki 1987), and Hokkaido (Iwata & Tajika 1989). The occurrence from Hokkaido (Iwata & Tajika 1989) is the northernmost limit of the range of *A. enesseffi* in the world. *Theocampe abschnitta* (Fig. 3I) was reported from the mid-Pacific Ocean (Empson-Morin 1981) and Southwest Japan (Muramatsu 1986; Yamasaki 1987). *Myllocercion acineton* (Fig. 3L) was reported from the mid-Pacific Ocean (Empson-Morin 1981), California (Foreman 1968), New Zealand (Hollis 1997), and the mid-Atlantic Ocean (Foreman 1978). *Dictyomitra lamellicostata* (Fig. 3H) was reported from the mid-Atlantic Ocean (Foreman 1977, 1978), California (Foreman 1968), New Zealand (Hollis 1997), and Southwest Japan (Suyari & Hashimoto 1985; Suyari 1986).

With respect to the relation between radiolarian distribution and latitude, *Amphipyndax enesseffi*, *Theocampe abschnitta*, *Myllocercion acineton*, and *Dictyomitra lamellicostata* were restricted to the low to intermediate latitudes except for New



○ *Stichomitra livermorensis* □ *Theocampe altamontensis* ☆ *Lithomelissa* sp.

FIG. 4. — Distribution of *Stichomitra livermorensis* (Campbell & Clark), *Lithomelissa* sp. (including *L. heros* Campbell & Clark and *L. hoplites* Foreman), and *Theocampe altamontensis* (Campbell & Clark) in the late Campanian to early Maastrichtian. Data are from Campbell & Clark (1944), Foreman (1968, 1977), Pessagno (1976), Empson-Morin (1984), Muramatsu (1986), Iwata & Tajika (1986, 1989), Vishnevskaya (1986), Yamasaki (1987), Ballance *et al.* (1989), Ling & Lazarus (1990), Ling (1991), Hollis (1997), and present research. This map has been synthesized from Barron *et al.* (1981), Smith *et al.* (1994), and Roberts & Kirschbaum (1995).



★ *Amphipyndax enesseffi* ● *Theocampe abschnitta* ▲ *Myllocercion acineton* ■ *Dictyomitra lamellicostata*

FIG. 5. — Distribution of *Amphipyndax enesseffi* Foreman, *Theocampe abschnitta* (Empson-Morin), *Myllocercion acineton* Foreman, and *Dictyomitra lamellicostata* Foreman in the late Campanian to early Maastrichtian. Data are from Pessagno (1969), Moore (1973), Empson-Morin (1981, 1984), Suyari & Hashimoto (1985), Muramatsu (1986), Suyari (1986), Yamasaki (1987), Iwata & Tajika (1989), Takahashi *et al.* (1989), Ishii *et al.* (1990), Hollis (1997), and present research.

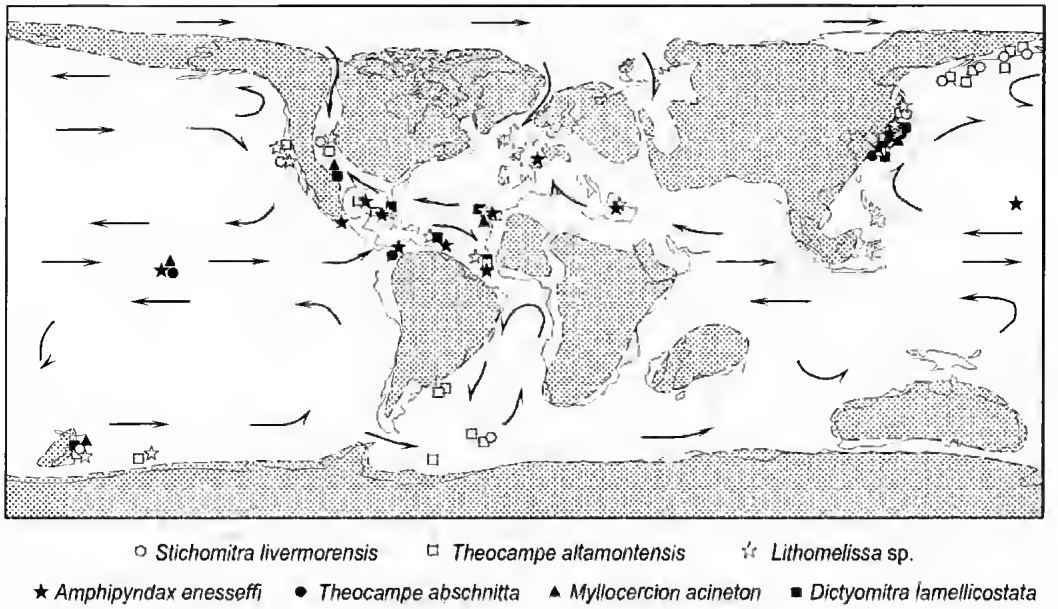


FIG. 6. — Relationship between Gordon's (1973) oceanic circulation and the global distribution of the seven characteristic radiolarian species. *Amphipyndax enesseffi*, *Theocampe abschnitta*, *Myllocercion acineton*, and *Dictyomitra lamellicostata* were restricted to the low to intermediate latitudes. *Lithomelissa heros*, *Lithomelissa hoplites*, *Theocampe altamontensis*, and *Stichomitra livermorensis* would tend to be cosmopolitan, however, only in the circum-Pacific region, they were apparently confined to northeastern Asia, northwestern North America, and the Antarctic. In the Tethys Sea and Atlantic Sea, there were more longitudinal channels which permitted mixing of their water with higher latitude water. Intermediate to high latitude radiolarians, therefore, reach much farther south to the Tethyan and central Atlantic regions along the seaways on the Laurasia. In contrast, circulation in the northern Pacific Ocean during the Late Cretaceous was dominated by a clockwise gyre. It made possibly contrasting distributions of radiolarians in this time.

Zealand (Hollis 1997). *Lithomelissa heros*, *Lithomelissa hoplites*, *Theocampe altamontensis*, and *Stichomitra livermorensis* would tend to be cosmopolitan. However, only in the circum-Pacific region, they were apparently confined to northeastern Asia, northwestern North America, and the Antarctic. That is, the paleobiogeographic distributions of the particular species of Late Cretaceous radiolarians seem to have reflected water-masses or their conditions.

Temperature is presumably a latitudinal component (e.g., Petrushevskaya 1971). Factors other than water depth and temperature such as nutrient levels and water chemistry undoubtedly controlled radiolarian distribution and abundance (e.g., Anderson 1983); many of these factors, however, are also related to water depth and temperature (Pessagno 1976). Among fossil organisms, the clearly latitudinal distribution of foraminifera in Cretaceous rocks indicates the importance of temperature (e.g., Caron 1985). Ammonoids also seem to be influenced by temperature as they are separable into Tethyan (tropical) and Boreal assemblages (e.g., Obata & Matsukawa 1988). If the faunal distributions of radiolarians are due to differences in temperature of the water masses, the distribution is possibly influenced by the current systems. Not only do currents separate biogeographical regions, but the currents themselves contain characteristic radiolarian faunas.

Using analogies with the modern world and evidence of past climates, Gordon (1973) reconstructed global ocean currents for the Late Cretaceous. Fig. 6 shows the relationship between Gordon's (1973) oceanic circulation and the global distribution of the seven characteristic radiolarian species.

Any discussion of Late Cretaceous paleoenvironments first requires a description of land-sea distribution, which was significantly different from the present (Barron *et al.* 1981; Smith *et al.* 1994). Global marine transgression progressed during Late Cretaceous time (e.g., Payton 1977).

The Tethys Sea and the Atlantic Ocean were broad at this time, and there were more longitudinal channels (the northern Tethys and northern Atlantic longitudinal seaways) which permitted mixing of their water with higher latitude water, not necessarily at the surface of the water column. The circumpolar West Wind Drift would have caused cool currents to enter the North American mid-continental seaway and the European shelf seas (Gordon 1973). Intermediate to high latitude radiolarians, therefore, reach much farther south to the Tethyan and central Atlantic regions along the seaways on the Laurasia. It was proved by bimodal radiolarian faunas found at the Late Cretaceous Tethyan and mid-Atlantic regions, and was clearly associated with the Late Cretaceous transgressive phase. Pessagno & Blome (1986) referred to Gordon's model as being applicable to the Middle Jurassic world oceanic circulations. They also recognized the mixing of warm and cool watermasses at the Tethyan and Atlantic regions in that time.

In contrast, circulation in the northern Pacific Ocean during the Late Cretaceous was dominated by a clockwise gyre (Gordon 1973), with a warm current (Paleo-Kuroshio Current) flowing north on its western margin where *Amphipyndax enesseffi*, *Theocampe abschnitta*, *Myllocercion acineton*, and *Dictyomitra lamellicostata* thrived, and a cool current (Paleo-California Current) flowing south on the eastern margin where *Lithomelissa heros*, *Lithomelissa hoplites*, *Theocampe altamontensis*, and *Stichomitra livermorensis* were successful. Around the Japanese Islands, two oceanic currents may have existed: one from the northernmost Pacific Ocean and the other from the Equator. They crossed each other at the present position of the Japanese Islands.

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APPENDIX

Sample localities

Figured specimens will be deposited in the Tokyo Gakugei University. The following sample numbers, Sh and St, refer to samples from the Shoya Formation and the Kobotoke Group, respectively. For St-1, see Loc. 8 in Takahashi *et al.* 1989; Loc. 12 in Ishii *et al.* 1990.

Samples	Geologic setting	localities
Sh-1	Siliceous dark gray mudstone	36°13'07"N, 138°35'04"E
Sh-2	Siliceous dark gray mudstone	36°13'07"N, 138°35'04"E
Sh-3	Siliceous dark gray mudstone	36°13'07"N, 138°35'04"E
Sh-4	Siliceous dark gray mudstone	36°12'51"N, 138°35'04"E
Sh-5	Siliceous dark gray mudstone	36°12'51"N, 138°35'04"E
St-1	Siliceous dark gray mudstone	35°53'39"N, 138°31'10"E
St-2	Siliceous black mudstone	35°46'06"N, 138°54'33"E

Permian Albaillellaria (Radiolaria) from a limestone lens at the Arrow Rocks in the Waipapa Terrane (Northland, New Zealand)

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KEY WORDS
Radiolaria,
Albaillellaria,
Permian,
New Zealand,
Waipapa Terrane,
Follicucullus,
Arrow Rocks,
new species.

ABSTRACT
Well-preserved Permian radiolarians are present in a limestone lens at Arrow Rocks in the Whangaroa Area within Waipapa Terrane, New Zealand. This fauna contains eight species of albaillellarians, six species of genus *Follicucullus* and two of *Pseudoalbaillella*, and is Late Middle to Early Late Permian in age. In the Whangaroa Area, basalts are probably as old as Middle Permian, while cherts are mostly Late Permian. Although the radiolarian fauna from Arrow Rocks contains two new species of *Follicucullus*, this fauna can nevertheless be assigned a low-latitude origin. Two new species, *Follicucullus sphaericus* and *Follicucullus whangaroaensis*, are described.

MOTS CLÉS
Radiolaire,
Ibaillellarides,
Permien,
Nouvelle Zélande,
Waipapa Terrane,
Follicucullus,
Arrow Rocks,
nouvelles espèces.

RÉSUMÉ
Albaillellaridés (radiolaires) permiens d'un banc calcaire à Arrow Rocks dans la Waipapa Terrane (Nouvelle Zélande septentrionale).
Des radiolaires permiens bien conservés ont été trouvés dans un banc calcaire à Arrow Rocks dans la région de Whangaroa de la Waipapa Terrane, Nouvelle Zélande. Cette faune contient huit espèces d'albaillellaridés, six espèces du genre *Follicucullus* et deux de *Pseudoalbaillella*, et est d'âge Permien moyen à début Permien supérieur. Dans la région de Whangaroa, les basaltes sont probablement aussi anciens que le Permien moyen, alors que les cherts sont principalement Permien supérieur. Bien que la faune à radiolaires à Arrow Rocks contiennent deux nouvelles espèces de *Follicucullus*, cette faune peut néanmoins être considérée comme de basse latitude. Deux nouvelles espèces, *Follicucullus sphaericus* et *Follicucullus whangaroaensis*, sont décrites.

INTRODUCTION

Our knowledge of Permian radiolarians has significantly increased since Ormiston & Babcock (1979) described genus *Follicucullus* from Guadalupian sequences in West Texas. After this pioneering research, taxonomy and biostratigraphy of Permian fauna developed rapidly in the United States, Russia and Japan (e.g., Holdsworth & Jones 1980; Ishiga & Imoto 1980; Takemura & Nakaseko 1981; Ishiga *et al.* 1982a, b; Nazarov & Ormiston 1986; Ishiga 1986). Most of this work was, however, done in the northern hemisphere, and most Permian radiolarians recorded from the southern hemisphere are from New Zealand.

Permian radiolarians are known from only a few fossil localities in New Zealand, one of which is Red Rocks near Wellington in Torlesse Terrane (Fig. 1), where Grapes *et al.* (1990) reported Middle Permian radiolarians from bedded chert. The other localities are concentrated within the Whangaroa Area in the northern Waipapa Terrane. Several radiolarian localities of bedded chert and limestone have been reported from this area, geologic age of which ranges from Middle to Late Permian (Caridroit & Ferrière 1988; Adachi 1988; Takemura *et al.* 1998).

We have made geological and biostratigraphic surveys in the Whangaroa Area (1995-1996), and have already reported the occurrence of Permian and Triassic radiolarians from this area. At Arrow Rocks, an almost continuous section from basalt with limestone, bedded chert to siliceous mudstone is exposed. Well-preserved radiolarians are present in a limestone lens within spilitic basalt, the age of which is Middle to Late Permian (Takemura *et al.* 1998). This fauna includes several albaillellarian species of the genera *Follicucullus* Ormiston & Babcock, 1979 and a

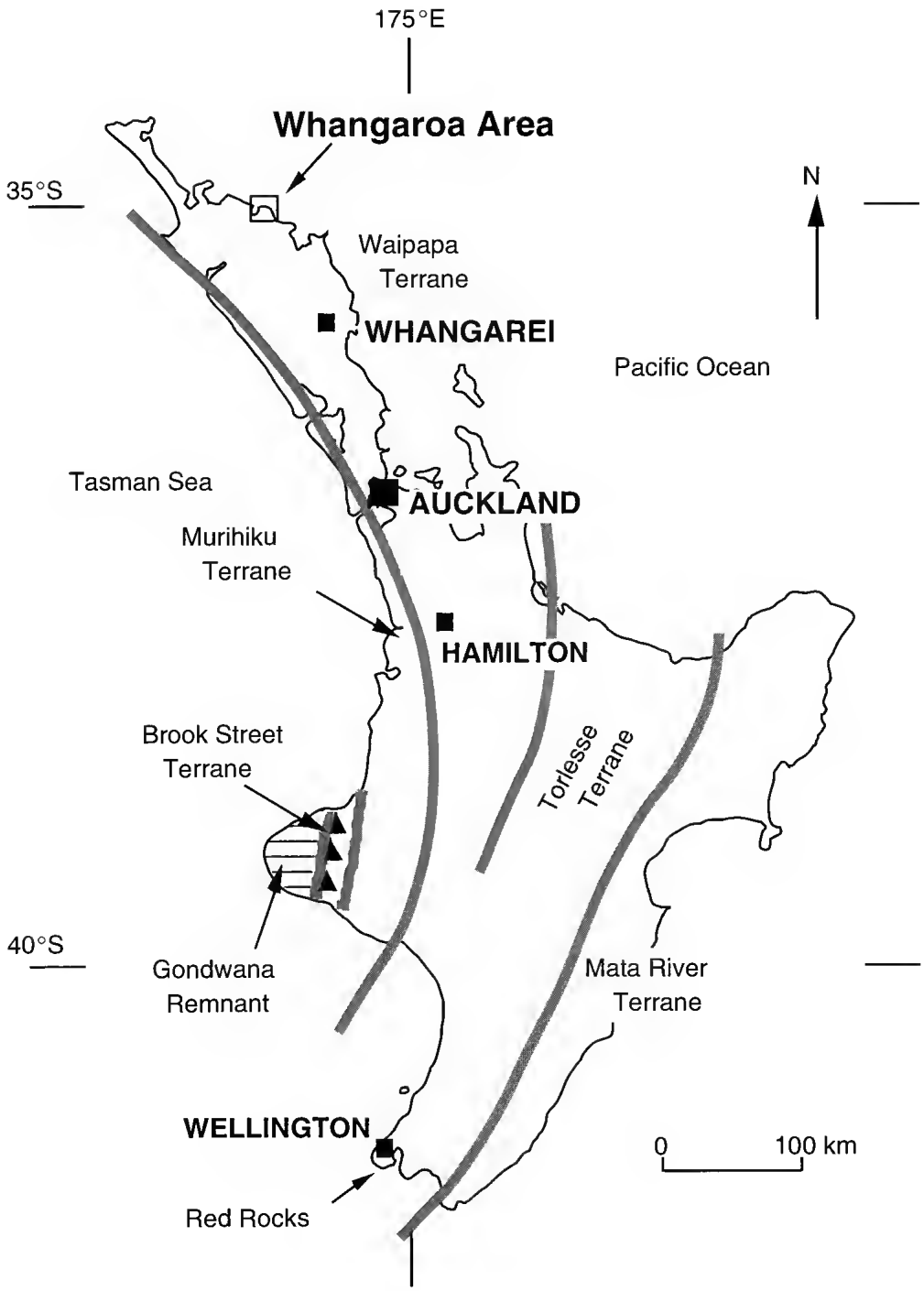

FIG. 1. — Index map of the North Island, New Zealand, showing the distribution of terranes (Aita & Spörli 1992) and the location of the Whangaroa Area, as well as Red Rock near Wellington.

few of *Pseudoalbaillella* Holdsworth & Jones, 1980. We describe albaillellarians of this fauna, including two new species of genus *Follicucullus*.

GEOLOGICAL SETTING, STRATIGRAPHY AND METHOD

Basement of New Zealand North Island consists mostly of five lithostratigraphic units, Murihiku, Dun Mountain, Waipapa, Torlesse and Mata River Terranes (Aita & Spörli 1992; Fig. 1). These terranes becomes younger in geological age from west to east, and the latter three, Waipapa, Torlesse and Mata River, are Mesozoic accretionary complexes.

The Whangaroa Area (Figs 1, 2) is situated at about 90 km northwest of Whangarei in Northland. This area belongs to the northern part of Waipapa Terrane, which is composed mostly of terrigenous clastic rocks associated with spilitic basalt, chert and argillites. Geological age of the northern part of this terrane is Permian to Triassic, based on radiolarians and fusulinids (Aita & Spörli 1992; Takemura *et al.* 1998).

The Waipapa Terrane rocks in the Whangaroa Area consists of massive to thick bedded sandstone (greywacke), spilitic basalt, bedded chert, green siliceous mudstone (argillite) and limestone lenses within basalt (Fig. 2). Prior to this study, more than six localities of Permian fossils were known from chert and limestone in this area. Radiolarian fossils show Middle to Late Permian age from five localities (Caridroit & Ferrière 1988; Adachi 1988; Takemura *et al.* 1998). Leven & Grant-Mackie (1997) described fusulinids from limestone lenses at Wherowhero Point (Fig. 2), the same locality from which Hornibrook (1951) reported fusulinids. They concluded that the fusulinid fauna belonged to *Yabeina-Lepidolina* zone and therefore is part of the Midian Stage of Tethyan Realm. They also mentioned the paleogeographic relationship of this fauna with eastern Asia. At Mahinepua Peninsula about 5 km east of the Wherowhero Point, very well-preserved Triassic radiolarians occur in the phosphatic nodules within green siliceous mudstone (Aita & Bragin 1999).

The material studied in this paper was obtained at Arrow Rocks (Oruatemanu Island), a small island located within Whangaroa Bay, north of Whangaroa Harbour (Fig. 2). The Grid Reference for Arrow Rocks, based on the New Zealand 1:50,000 topographic map, is PO4 & QO4/837895 corresponding to latitude 34°59.7'S and longitude 173°46.8'E. On this small island, we have observed a 135 m thick seemingly continuous section composed of spilitic basalt with limestone layers, bedded chert, and red, maroon and green siliceous mudstones. Takemura *et al.* (1998) made a preliminary report on the lithostratigraphy of this sequence, and divided it into eight lithological units (Fig. 3). Field observation of lithologies and thickness in these units in ascending order is as the follows:

– Unit 1: spilitic basalt with limestone lenses, 31.5 m;
– Unit 2: bedded chert, 11 m;
– Unit 3: alternation of chert and black shale, 1 m;
– Unit 4: red siliceous mudstone and red chert with manganese-rich layers, 6.6 m;
– Unit 5: red siliceous mudstone with thin red chert, 17.2 m;
– Unit 6: maroon chert and siliceous mudstone, 29.5 m;
– Unit 7: alternation of maroon and green siliceous mudstone, 11.2 m;
– Unit 8: green siliceous mudstone with vitric tuffs, 27 m.

Within this sequence, we observed no significant faulting except between Units 2 and 3. Boundaries between the units described above are conformable and appear to represent continuous deposition.

Takemura *et al.* (1998) report the occurrence of Late Permian Radiolaria including *Albaillella triangularis* Ishiga, Kito & Imoto, 1982 and *Hegleria* sp. in a bedded chert sample (ARR-7) within Unit 2. The horizon of ARR-7 lies about 10 m above that of ARR-1 (Fig. 3). Triassic radiolarians such as *Parentactinia* (Dumitrica, 1978), *Archaeosemantis* (Dumitrica, 1978) and forms belonging to genus *Glomeropyle* (Aita & Bragin 1999) are present in siliceous mudstones within Units 6 and 8.

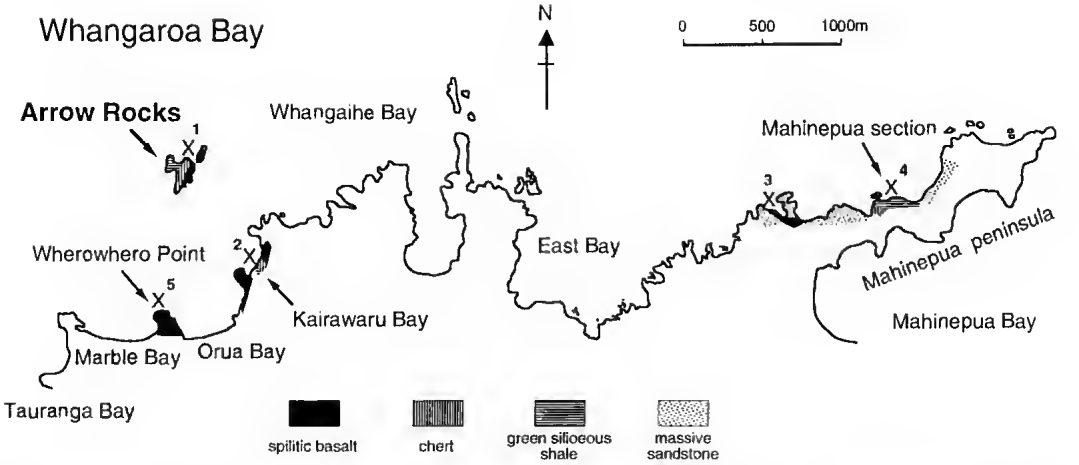

FIG. 2. — Permian and Triassic fossil localities in the Whangaroa Area. **X**, fossil localities, **1**, Permian radiolarians from limestone and bedded chert at Arrow Rocks (Takemura *et al.* 1998 and this study); **2**, Permian radiolarians from bedded chert at Kairawaru Bay (Caridroit & Ferrière 1988; Adachi 1988); **3**, Permian radiolarians from limestone and chert at west of Mahinepua Peninsula (Takemura *et al.* 1998); **4**, Triassic radiolarians from phosphate nodules in green argillite at the Mahinepua Section (Aita & Bragin 1999); **5**, Permian fusulinids from limestones at Wherowhero Point (Hornibrook 1951; Leven & Grant-Mackie 1997).

The material treated in this study is a limestone lens (ARR-1) within Unit 1. The unit includes four red, pale red or white limestone layers, 0.7 to 2 m thick, intercalated within basalts, which are usually green grey to green coloured, massive or showing pillow structure, or sometimes are fragmental. ARR-1 is a purple grey coloured, laminated limestone lens, situated at about 24 m above the base horizon. This lens is intercalated just below the uppermost red limestone layer within Unit 1 (24-26 m, Fig. 3).

ARR-1 contains numerous radiolarian shells, but they have been altered by $CaCO_3$ so that we obtained no or very few residues by extraction using diluted hydrochloric, nitric or acetic acids. As a result of this, it was decided to process the sample using diluted hydrofluoric acid (HF, 1 to 3%) for about 20 hours. We successfully recovered residues including radiolarians by this process, but the preservation was not good enough for determination of species. The same sample was then again processed by diluted nitric acid (HNO_3, 1 to 2%) for up to 24 hours. After this step, we were able to obtain well-preserved radiolarian shells. Although other acids such as hydrofluoric, hydrochloric or acetic acids were tried for the second step after HF, the best preservation was achieved by using nitric acid.

RADIOLARIAN FAUNA FROM ARROW ROCKS AND GEOLOGIC AGE OF BASALT-CHERT SEQUENCE IN THE WHANGAROA AREA

The limestone lens sample (ARR-1) contains well-preserved albaillellarian fauna. The fauna includes six species of genus *Follicucullus* and two of genus *Pseudoalbaillella* (Figs 4, 5). Ishiga (1986, 1991) established Permian radiolarian zonation based on the ranges of albaillellarians from mostly bedded chert sequences in Southwest Japan. His zonation is applicable for the ARR-1 fauna, because many albaillellarians from our sample were already included within Ishiga's zonation.

Among these albaillellarians with conical shells investigated by Ishiga (1986, 1991), *Pseudoalbaillella fusiformis* (Holdsworth & Jones, 1980), *P.* aff. *longicornis* of Ishiga *et al.* (1982a), *Follicucullus scholasticus* Ormiston & Babcock, 1979 and *F. porrectus* Rudenko, 1984 (= *F. japonicus* of Ishiga 1991) are present in our sample ARR-1. Because both *Follicucullus monacanthus* Ishiga & Imoto, 1982 (Ishiga *et al.* 1982b) and species of genus *Neoalbaillella* Takemura & Nakaseko, 1981 are absent in this sample, we correlate this fauna with *Follicucullus scholasticus* zone of Ishiga (1986).

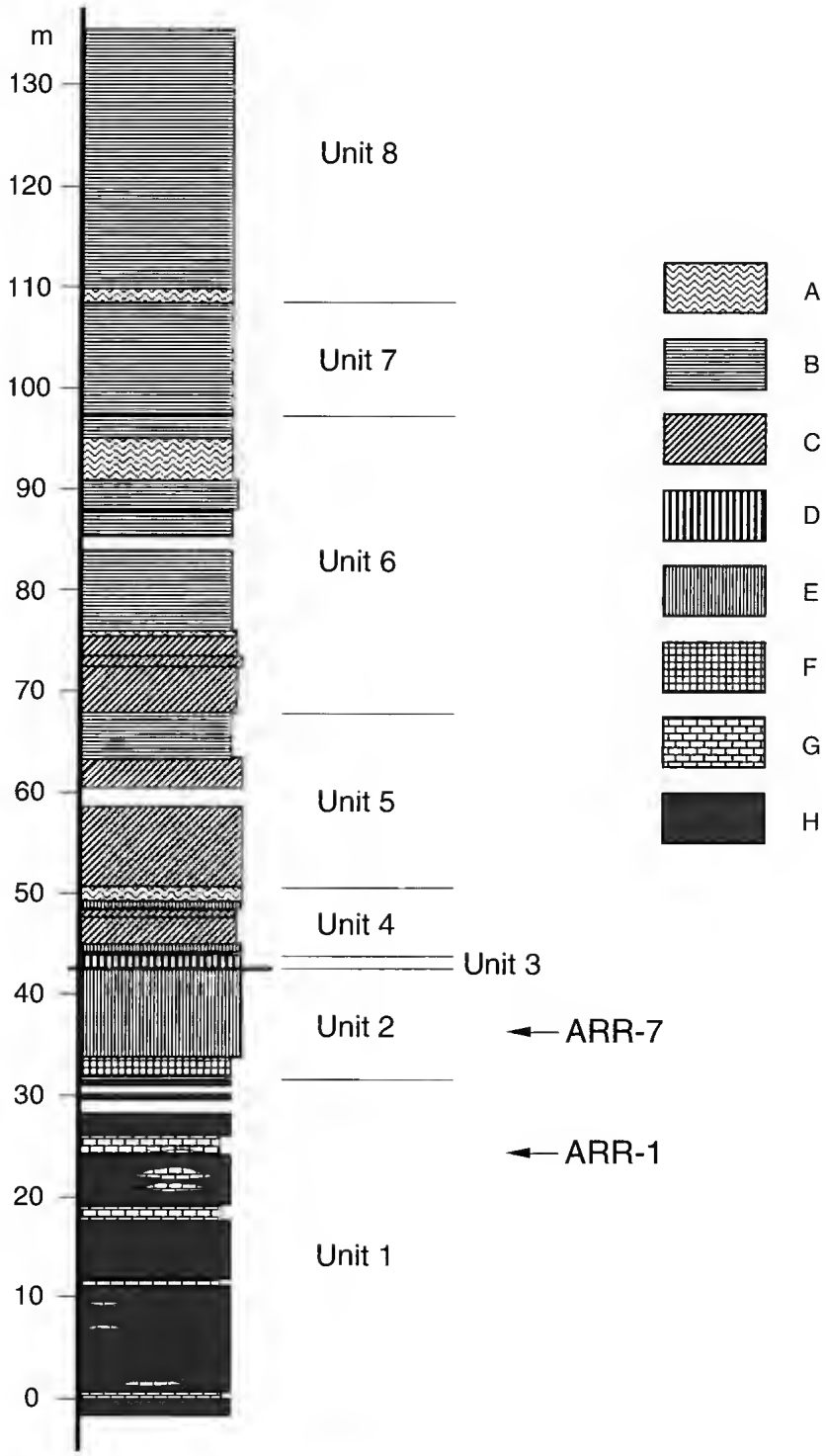

FIG. 3. — Summarized geologic column of the Arrow Rocks. **A**, fold zone; **B**, siliceous mudstone; **C**, bedded siliceous mudstone and chert; **D**, alternation of black shale and chert; **E**, bedded chert; **F**, tuff; **G**, limestone; **H**, spilitic basalt. ARR-1 and ARR-7 are the horizons where Permian radiolarians occurred (Takemura *et al.* 1998).

Following Ishiga's zonation, the upper limits of the ranges of *Pseudoalbaillella fusiformis* and *P.* aff. *longicornis* are within *Follicucullus monacanthus* zone or lower. However, occurrences of these two species in ARR-1 are few and they are usually less well preserved than *Follicucullus*. It is possible that these two species might be reworked, or that the ranges might be longer than that suggested by Ishiga's (1986) zonation.

The fauna in ARR-1 can be also correlated to the *Follicucullus japonicus* zone of Ishiga (1991) because of the co-occurrence of *F. porrectus* (= *F. japonicus*) and *F. scholasticus*, and because of the absence of *F. monacanthus*, *F. charveti* Caridroit & De Wever, 1984, *F. bipartitus* Caridroit & De Wever, 1984 and *Neoalbaillella*. According to the correlation of radiolarian zonation with fusulinid and conodont zonations by Ishiga (1986, 1990, 1991), the geologic age of *Follicucullus scholasticus* zone and *F. japonicus* zone is in the vicinity of the boundary between Middle and Late Permian.

Besides these species, Kozur (1993) described *Cariver dorsoconvexus* (herein treated as a species of the genus *Follicucullus*) from Upper Permian sequence in Sicily, Italy. *F. sphaericus* n. sp. was figured by Kuwahara (1997) as *Follicucullus* sp. A, which is present in bedded chert of GA section in Gujo-Hachiman Area, central Japan. These samples are within *Neoalbaillella optima* and *N. ornithoformis* zones, indicating a Late Permian age. The ranges of these two species, *Follicucullus dorsoconvexus* and *F. sphaericus* n. sp., however, are not clarified yet. Therefore, we regard the geologic age of our sample ARR-1 as Late Middle or Early Late Permian.

Takemura *et al.* (1998) reported Permian radiolarians from a limestone lens (MAH-5) at the west end of Mahinepua Peninsula (Fig. 2). MAH-5 contains *Follicucullus porrectus* Rudenko and *Pseudoalbaillella* (?) sp. They correlated this sample with the *F. monacanthus* zone of Ishiga (1986), and with the *F. japonicus* zone of Ishiga (1991), because of the absence of other species of *Follicucullus*. The geologic age of this sample is also near the Middle/Late Permian boundary.

Recently Leven & Grant-Mackie (1997) described fusulinids from some limestone lenses within spilitic basalt at Wherowhero Point (Fig. 2). These fusulinids include *Lepidolina shiraiwensis* Ozawa, 1925, *Neoschwagerina margaritae* Deprat, 1913 and *Yabeina globosa* (Yabe, 1906), and the fauna was correlated with the *Yabeina-Lepidolina* zone. Leven & Grant-Mackie (1997) regard the geologic age of these fusulinids as Midian, and most samples probably as Early Midian. The Midian stage corresponds to the Capitanian and late Wordian in North America (Leven & Grant-Mackie, 1997) and Ishiga (1990) correlated the fusulinid *Yabeina-Lepidolina* zone with the radiolarian *Follicucullus monacanthus* and *F. scholasticus* zones.

Thus, the three limestone samples within spilitic basalts from northern New Zealand show similar geologic ages. Bedded cherts are sometimes associated with these basalts and are characteristic of ocean floor sedimentary sequences. Indeed, at Arrow Rocks, bedded cherts comformably overlie spilitic basalt (Fig. 3). The ages of these cherts are reported from three localities in the Whangaroa Area (Caridroit & Ferrière 1988; Adachi 1988; Takemura *et al.* 1998) to be about Late Permian. Therefore, the age of ocean floor sequence represented by basalt and chert in the Whangaroa Area is Middle to Late Permian.

The radiolarian fauna from Arrow Rocks contains two new species of *Follicucullus*, *F. sphaericus* n. sp. and *F. whangaroaensis* n. sp. The former was already figured by Kuwahara (1997) from Japan, but the latter has not been reported yet. These two species are common elements within this fauna, and they may reflect a significant faunal difference in albaillellarian distribution between New Zealand and northern hemisphere regions.

Leven & Grant-Mackie (1997), however, also maintained that the fusulinid fauna from Wherowhero Point showed a clear affinity with those in the eastern Paleotethys and Panthalassa region, and that these limestone blocks had been moved from the original site of deposition. Because the radiolarian-bearing limestones which we describe herein show similar geologic age as these fusulinid limestones, and because they all occur within a restricted area, the radiolarian fauna from these samples must originate from near the region where the fusulinids were deposited. Therefore, the radiolarian fauna from Arrow

Rocks originated in a low-latitude area of Middle to Late Permian time.

SYSTEMATIC DESCRIPTION

The following description was made by the first author, Takemura A. The type specimens are deposited at Hyogo University of Teacher Education.

Subclass RADIOLARIA Müller, 1838
Order POLYCYSTINA Ehrenberg, 1838
emend. Riedel, 1967
Suborder ALBAILLELLARIA Deflandre, 1953
emend. Holdsworth, 1969

Family ALBAILLELLIDAE Deflandre, 1952
emend. Holdsworth, 1977

REMARKS
Cheng (1986) classified Albaillellaria into two groups, Albaillellacea and Follicucullacea, based on the presence of a cross-bar. This criterion is, however, applicable only for very well-preserved specimens, and we cannot observe such fragile parts in most Permian samples.
Kozur (1981, 1993) and Kozur & Mostler (1989) described many genera for Permian albaillellarians with conical shells. His classification seems to be so minute that sometimes we cannot make generic assignment. In this paper, the first author therefore adopts four genera for Permian albaillellarians, *Albaillella* Deflandre, 1952, *Pseudoalbaillella* Holdsworth & Jones, 1980, *Follicucullus* Ormiston & Babcock, 1979, and *Neoalbaillella* Takemura & Nakaseko, 1981, same as Ishiga & Imoto (1980), Ishiga (1982) and Ishiga *et al.* (1982a, b).

Genus *Follicucullus*
Ormiston & Babcock, 1979

Follicucullus Ormiston & Babcock, 1979: 332.
Ishigaconus Kozur & Mostler, 1989: 181-182.
Cariver Kozur, 1993: 108-109.
Lacisus Kozur, 1993: 109.

TYPE SPECIES. — *Follicucullus ventricosus* Ormiston & Babcock, 1979.

REMARKS
Most Permian taxonomic works followed the original definition of Genus *Follicucullus* made by Ormiston & Babcock (1979). Only Kozur & Mostler (1989) and Kozur (1993) divided this group, with descriptions of three new genera. However, their division are so minute that we cannot use them to assign a genus to poorly preserved specimens. Therefore, for this paper, the author regards these three genera as junior synonyms of the genus *Follicucullus*.
The author generally follows the specific division of *Follicucullus* established by Ishiga (1991), who lumped forms of this genus into six species from Permian sediments in Japan. They are *F. monacanthus* Ishiga & Imoto, 1982 (Ishiga *et al.* 1982b), *F. ventricosus* Ormiston & Babcock, 1979, *F. charveti* Caridroit & De Wever, 1984, *F. scholasticus* Ormiston & Babcock, 1979, *F. porrectus* Rudenko, 1984 (= *F. japonicus* Ishiga, 1991) and *F. bipartitus* Caridroit & De Wever, 1984. Other than these forms, three species *F. dorsoconvexus* (Kozur, 1993), *F. sphaericus* n. sp. and *F. whangaroaensis* n. sp. were distinguished in the sample ARR-1.

Follicucullus scholasticus
Ormiston & Babcock, 1979
(Fig. 4A, B)

Follicucullus scholasticus Ormiston & Babcock, 1979: 333-334, pl. 1, figs 1-5.
Follicucullus scholasticus Ormiston & Babcock morphotype I – Ishiga 1985: 180, 181, pl. 1, figs 15-21.

REMARKS
Ishiga (1984) proposed two morphotypes within this species. *F. scholasticus* morphotype I has simple conical shell without undulation and it resembles forms described by Ormiston & Babcock (1979) under the name of this species (Ishiga 1985). In this paper, the author follows Ishiga's taxonomy and *F. scholasticus* is used for forms with simple conical shell without undulation.
Kozur & Mostler (1989) proposed a new genus *Ishigaconus* for *Follicucullus* forms without shell undulation. However, the distinction of this species and *F. porrectus* is sometimes difficult because

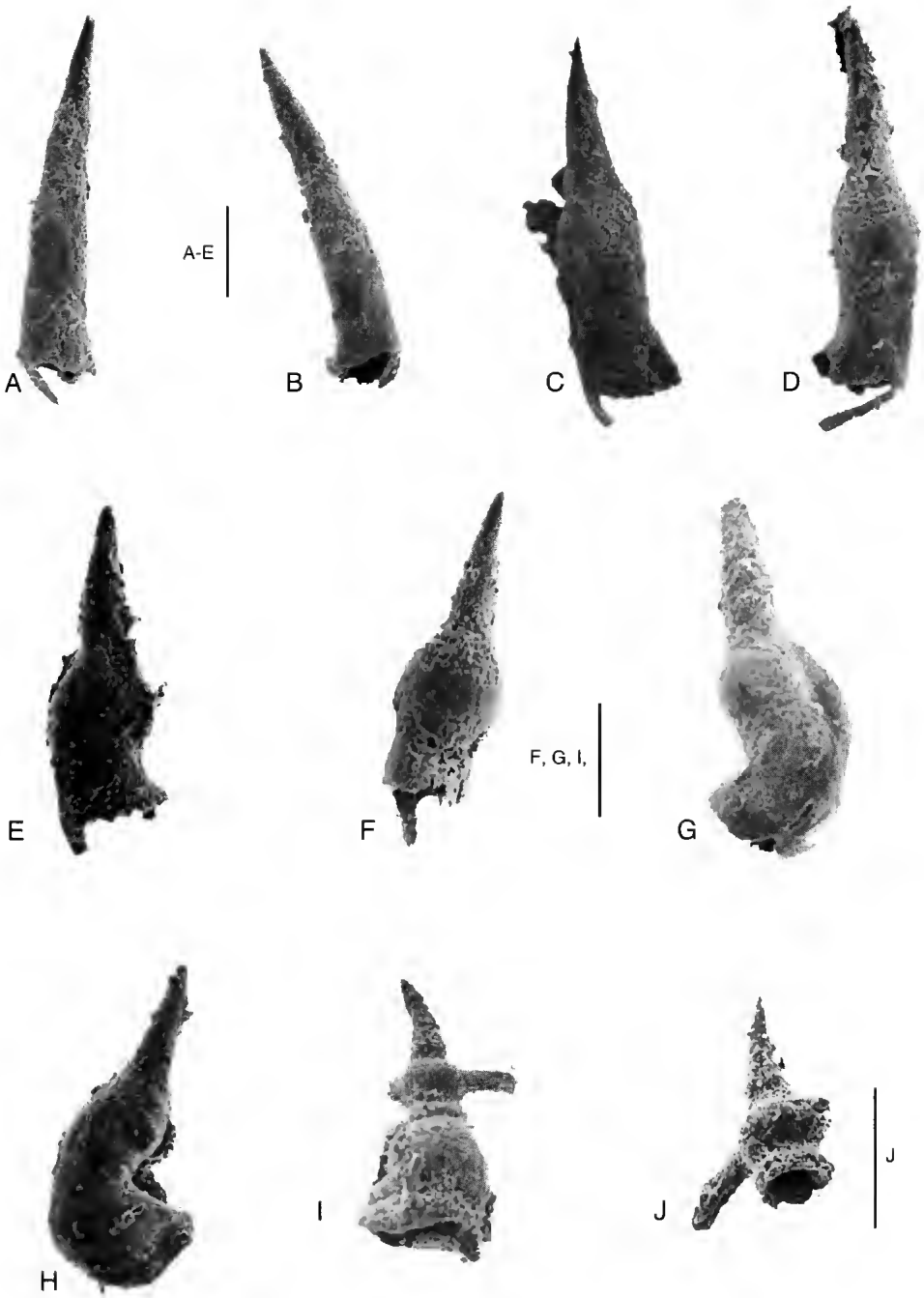

FIG. 4. — **A**, *Follicucullus scholasticus* Ormiston & Babcock, 1979; **B**, *Follicucullus scholasticus* Ormiston & Babcock, 1979; **C**, *Follicucullus porrectus* Rudenko, 1984; **D**, *Follicucullus porrectus* Rudenko, 1984; **E**, *Follicucullus ventricosus* Ormiston & Babcock, 1979; **F**, *Follicucullus ventricosus* Ormiston & Babcock, 1979; **G**, *Follicucullus dorsoconvexus* (Kozur, 1993); **H**, *Follicucullus dorsoconvexus* (Kozur, 1993); **I**, *Pseudoalbaillella fusiformis* (Holdsworth & Jones, 1980); **J**, *Pseudoalbaillella* aff. *longicornis* Ishiga & Imoto, 1980. Scale bars: 100 µm.

the undulation or tripartite division of shells is often unclear.

Follicucullus porrectus
Rudenko, 1984
(Fig. 4C, D)

Follicucullus porrectus Rudenko, 1984 – Beljanskij, Nikitina & Rudenko 1984, pl. 8, figs 3, 10.
Follicucullus scholasticus Ormiston & Babcock morphotype II – Ishiga 1984: 430, 431, pl. 1, figs 1-8.
Follicucullus japonicus Ishiga, 1991: 108-111, pl. 1, figs 1-22, pl. 2, fig. 1.

REMARKS
In this paper, the author uses this species name for intermediate forms between *F. scholasticus* and *F. ventricosus*. There are much variations of shell shapes within this species from sample ARR-1, same as described by Ishiga (1991). Such variations seem to be continuous from simple conical shape of *F. scholasticus* to clearly tripartite *F. ventricosus* with inflated spherical pseudothorax. Therefore, it is sometimes difficult to distinguish this species from the other two species.

Follicucullus ventricosus
Ormiston & Babcock, 1979
(Fig. 4E, F)

Follicucullus ventricosus Ormiston & Babcock, 1979: 332-333, pl. 1, figs 6-14.

REMARKS
Ishiga (1991) made a comparison between *F. porrectus* (= *F. japonicus*) and *F. ventricosus* under the description of the former species. He used the width/length ratio (W/L) of shells, strongly inflated pseudothorax and existence of groove (sinus) on pseudothorax as criteria to distinguish these two species.
F. ventricosus of the present study has strongly inflated and subspherical pseudothorax and a distinctly tripartite conical shell. However, there is usually no groove on the dorsal side of pseudothorax as seen in *F. dorsoconvexus*. The author tentatively include tripartite forms without grooves on subspherical pseudothorax within *F. ventricosus* in this paper. The difference between this species and *F. porrectus* is only the degree of inflation of the pseudothorax, and the variation between them seems to be continuous.

Follicucullus dorsoconvexus
(Kozur, 1993)
(Fig. 4G, H)

Cariver dorsoconvexus Kozur, 1993: 109, pl. 1, figs 15-17, 19.

REMARKS
Kozur (1993) proposed a new genus *Cariver* for *Follicucullus* species with curved shell and aperture perpendicular to the shell axis. If we adopt such minute generic division, we can assign genera only for well-preserved specimens.
F. dorsoconvexus resembles to *F. ventricosus*. Both two species have tripartite shell with inflated pseudoabdomen and sinus on the dorsal side of the shell. The aperture is sometimes not exactly perpendicular to the shell axis, because the dorsal side of the shell wall becomes shorter (Fig. 4G).

Follicucullus sphaericus
Takemura, n. sp.
(Figs 5A-F, 6)

Follicucullus sp. A. – Kuwahara 1997, pl. 2, fig. 8.
Follicucullus (?) sp. – Takemura *et al.* 1998, pl. 1, fig. 13.

TYPES. — Holotype HUTE-R-4024 (Fig. 5A), paratypes HUTE-R-4025 (Fig. 5B) and HUTE-R-4026 (Fig. 5D).

ETYMOLOGY. — The species name was derived from the characteristic shape of this species.

MEASUREMENTS. — Length of shell, 260-350 µm; length of upper conical part, 120-180 µm; width of shell, 160-230 µm; width of the base of upper conical part, 50-110 µm; measured in 28 specimens.

DESCRIPTION
Imperforate and smooth shell composed of two parts, upper conical part and lower part with flattened hemispherical shape. The upper conical part slender, and straight or sometimes slightly curved dorsally. The lower portion of this cone often slightly inflated. The inflated and curved lower part large with smooth surface and

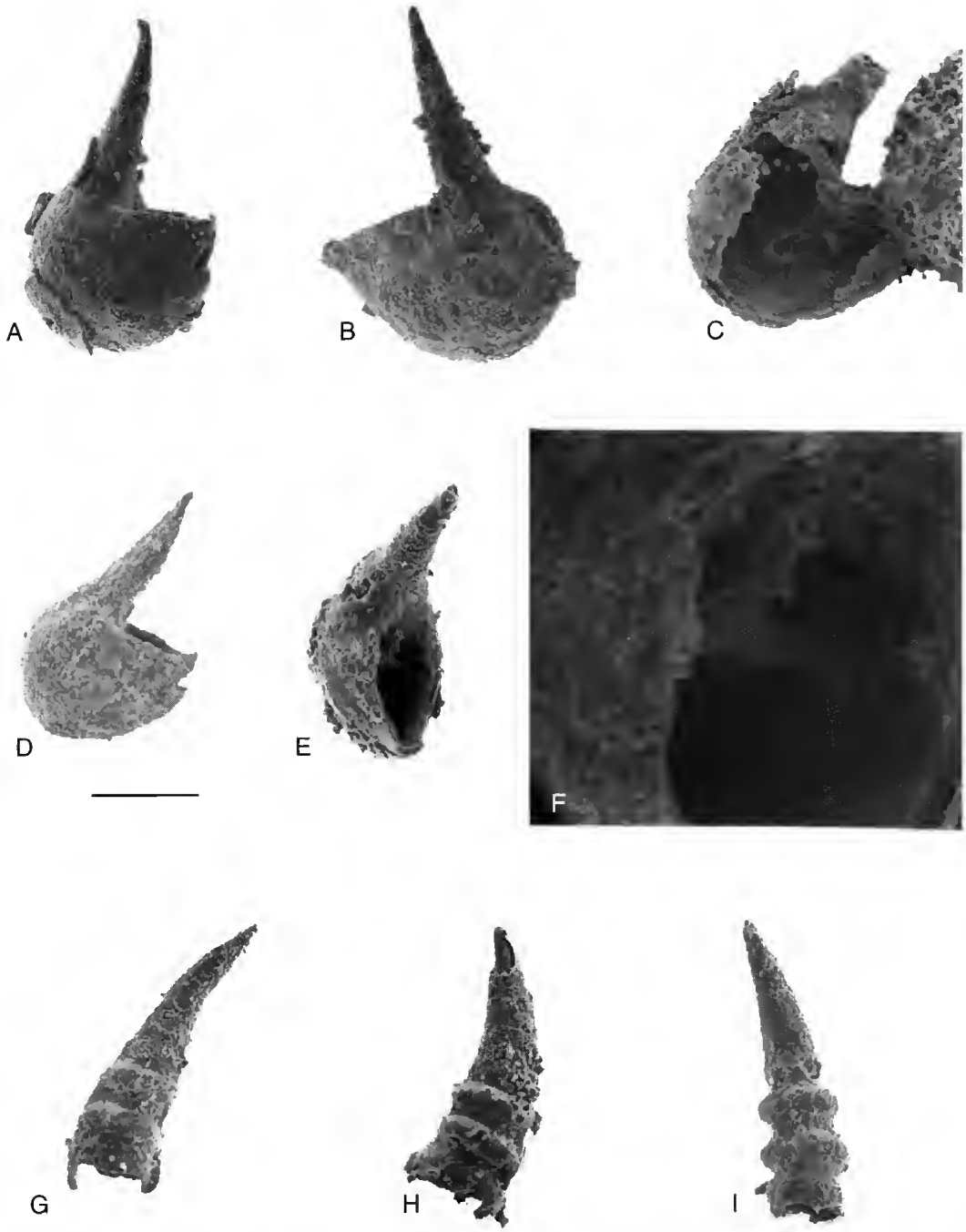

FIG. 5. — **A**, *Follicucullus sphaericus* n. sp., right lateral view, holotype (HUTE-R-4024); **B**, *Follicucullus sphaericus* n. sp., left lateral view, paratype (HUTE-R-4025); **C**, *Follicucullus sphaericus* n. sp., a broken specimen showing the inner surface of the inflated lower part, a hook-shaped trace of the inner wall can be observed; **D**, *Follicucullus sphaericus* n. sp., right lateral view, paratype (HUTE-R-4026); **E**, **F**, *Follicucullus sphaericus* n. sp., apertural view of partly broken specimen, a tube-like ventral spine arises upward from the edge of bended wall; **G**, *Follicucullus whangaroaensis* n. sp., right lateral view, holotype (HUTE-R-4027); **H**, *Follicucullus whangaroaensis* n. sp., left lateral view, paratype (HUTE-R-4028); **I**, *Follicucullus whangaroaensis* n. sp., ventral view, paratype (HUTE-R-4029). Scale bar: A, B, D, E, G-I, 100 µm; C, 83 µm; F, 20 µm.

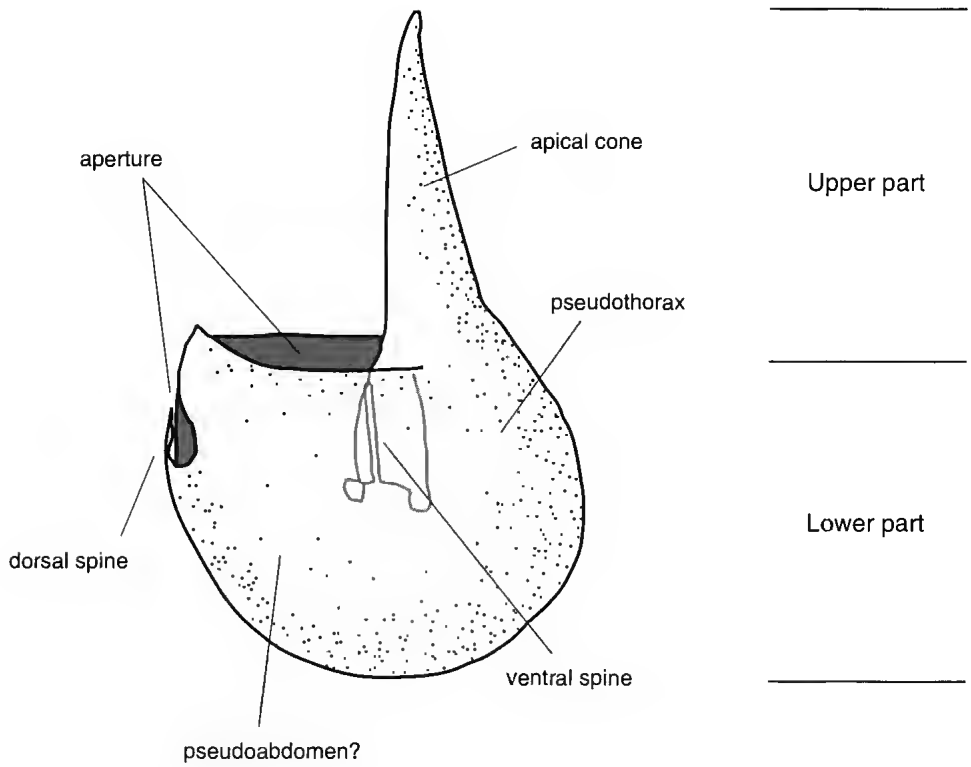

FIG. 6. — Schematic diagram of *Follicucullus sphaericus* n. sp. The inflated lower part of the shell is so strongly curved that the aperture opens upward. Within the inflated lower part, the shell wall of ventral side is curved and turned upward. Then, both dorsal and ventral spines also extend upward.

showing a semicircular shape in lateral view. Two apertures present on the lower part. A large aperture situated at the ventral side of the upper conical part and opening upward. This large aperture subelliptical in shape and tapering distally from the upper part. One more small aperture opening at the distal end of the shell in well-preserved specimens. This small aperture teardrop-shaped and opening toward the ventral side of the shell, with small dorsal spine or flap originating the lower end of this aperture. Inside the shell wall of the inflated and curved lower part, the ventral side of the shell wall of conical part strongly curved and turned upward. Tube-like ventral spine extending upward from the center of the turned end of the wall.

REMARKS

In the broken specimen (Fig. 5C), the trace of the shell wall could be observed on the inner surface of the lower inflated part of the shell. The trace is smoothly continuous from the upper conical part and somewhar inflated within the lower part, which resembles the inflated pseudothorax of *F. porrectus* or *F. ventricosus*. Then, the trace is curved strongly and turned upward.

From the turned end of this wall, cylindrical tube-like spine is arises upward inside the shell wall (Figs 5E, F, 6). This skeleton is homologous wirh a ventral spine or flap of other *Follicucullus* species. A small dorsal flap also exists below the small aperture on the distal part of the lower shell.

The upper conical part often shows slight inflation on its lower portion similar to the pseudothorax of *F. porrectus* or *F. ventricosus*. Therefore, the upper conical part of *F. sphaericus* n. sp. is homologous either with the apical corn alone or with both apical cone and upper pseudothorax of the other *Follicucullus* species. The lower shell

shape of this new species was formed by the strong bending and inflating of the pseudothorax and pseudoabdomen of the other species like *F. porrectus* or *F. dorsoconvexus*.

F. sphaericus n. sp. differs from all the other species of *Follicucullus* in its flattened hemispherical and curved shell shape, its aperture opening upward, and both ventral and dorsal flaps arising upward. The characteristic shape of this species resembles that of *Pseudoalbaillella bulbosa* Ishiga (Ishiga 1982: 335, pl. 1, figs 8-13, 16, 17). The strongly inflated and curved pseudoabdomen of *P. bulbosa* is quite similar to the lower part of *F. sphaericus* n. sp., except for a small flap of the former species. *F. sphaericus* n. sp. does not have pseudothorax and wings observed in *Pseudoalbaillella*. *P. bulbosa* ranges from Late Carboniferous to Early Permian in age, and there should be no direct phylogenetic relationship between these two species. *F. sphaericus* n. sp. should be evolved from the other *Follicucullus* species like *F. porrectus* or *F. dorsoconvexus*.

Follicucullus whangaroaensis
Takemura, n. sp.
(Fig. 5G-I)

Follicucullus sp. – Takemura *et al.* 1998, pl. 1, fig. 14.

TYPES. — Holotype HUTE-R-4027 (Fig. 5G), paratype HUTE-R-4028 (Fig. 5H) and HUTE-R-4029 (Fig. 5I).

ETYMOLOGY. — The species name is after Whangaroa Area in Northland, New Zealand, where Arrow Rocks is located.

MEASUREMENTS. — Length of shell, 240-330 µm; length of apical cone, 130-180 µm; width of shell, 70-110 µm; width of the base of apical cone, 60-70 µm; measured in 12 specimens.

DESCRIPTION

Imperforate conical shell slightly curved ventrally, and undulated at the lower part with two distinct inflated rings. Apical cone with smooth surface and with a length more than half of the total shell. Apical cone slightly flattened laterally and curved ventrally. In some specimens, vague ring-like inflation observed at the lowest part of apical cone. The lower part of the shell distinctly undulated in dorsal or ventral view. Two rings inflated laterally between apical cone and apertural region, with circular shape in transverse section. Distinct furrows existing between the two rings, and between the lower ring and inflated apertural region. In dorsal or ventral view, shell distinctly undulated because of these rings and furrows. A vague furrow may divide apical cone and the upper ring. These furrows not present or becoming weak at the dorsal and ventral sides of this ring region. The outline of the shell not undulated distinctly in lateral view. The apertural region, the lowermost part of conical shell, inflated like rings. Two small spines or flaps, dorsal and ventral ones, arising obliquely downward.

REMARKS

F. whangaroaensis n. sp. differs from the other species of *Follicucullus* by its banded lower shell. This kind of rings has never been observed in the other *Follicucullus* species. The author included this new species within genus *Follicucullus* because of the similarity of its shell shape to other *Follicucullus*, such as *F. scholasticus* or *F. porrectus*. The ring region of this species may correspond with inflated pseudothorax of the other species. Similar structure to this undulated shell with rings was observed in the pseudoabdomen of *Pseudoalbaillella globosa* Ishiga & Imoto (Ishiga *et al.* 1982b). *P. globosa* has one ring and inflated apertural region below the spherical pseudothorax with two wings. The author considers that there is no direct phylogenetic relationship between these two species.

Genus *Pseudoalbaillella*
Holdsworth & Jones, 1980

Pseudoalbaillella Holdsworth & Jones, 1980: 284. – Ishiga, Kito & Imoto 1982b: 274, 275.

TYPE SPECIES. — *Pseudoalbaillella scalprata* Holdsworth & Jones, 1980.

REMARKS

Ishiga & Imoto (1980), Ishiga (1982) and Ishiga *et al.* (1982a, b) assigned this genus for Late

Paleozoic albaillellarians with conical, usually imperforate and tripartite shells and with two wings on the inflated pseudoabdomen. The author follows their taxonomy of this genus.

Pseudoalbaillella fusiformis
(Holdsworth & Jones, 1980)
(Fig. 4I)

Parafollicucullus fusiformis Holdsworth & Jones, 1980: 285, figs D, E.
Pseudoalbaillella fusiformis (Holdsworth & Jones) – Ishiga, Kito & Imoto 1982b: 275, 276, pl. 4, figs 10-12.

REMARKS
Most specimens of this species extracted from ARR-I are more or less broken. The preservation of this species seems to be worse than that of *Follicucullus*.
Holdsworth & Jones (1980) described this species as *Parafollicucullus fusiformis* and they regarded the existence of a ring-like prepseudoabdominal segment as a criterion of this genus. However, some specimens from ARR-1 have no ring on their pseudoabdomen.

Pseudoalbaillella aff. *longicornis*
Ishiga & Imoto, 1980
(Fig. 4J)

Pseudoalbaillella sp. aff. *P. longicornis* Ishiga & Imoto – Ishiga, Kito & Imoto 1982a: 18, pl. 3, fig. 11; 1982b: 275, pl. 2, figs 1-7.

REMARKS
Most specimens of this form are broken and their preservation is usually poor. The total shape and size of this form is almost same as the upper half of *P. fusiformis*.

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